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The energy prosumer:

assessing the variability of returns of prosumers and their influence on large producers' risks

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TABLE OF CONTENTS

List of figures III

List of tables III

List of acronyms IV

Summary VI

1 Introduction 1

2 Literature review 5

2.1 Specifying the prosumer 5

2.2 What is risk? 6

2.3 Risk profile of prosumers 6

2.4 Risks for electricity prosumers 9

2.5 Risk management possibilities for PV prosumers 16

2.6 Risks for large-scale electricity producers 17

2.7 Risk management for large electricity producers 21

2.8 Concluding remarks 21

3 Methodology and data 24

3.1 Prosumer risk analysis 24

3.2 Influence of prosumers on large producers 28

4 Results 33

4.1 Results for risk of prosumer cash flows 33

4.2 Influence of prosumers on large producers' revenue volatility 35

5 Discussion, conclusion and future research 37

5.1 Discussion 37

5.2 Conclusion 38

5.2 Future research 39

References 41

Appendix I: Transcript of prosumer interview 59

Appendix II: Data and additional graphs for prosumer risk analysis..................................... 65

Appendix III: Data for the influence of prosumers on large producers 75

List of figures

Figure 1: Comparison of electricity flow without and with prosumers 2

Figure 2: Comparison of risk profile derivation of e-commerce and electricity prosumer ... 23

Figure 3: Installed PV capacity and PV power produced (2015-2018) 31

Figure 4: Monthly electricity consumption, market demand and price (2015-2018) 32

Figure 5: Average cash flows per month for all scenarios 34

Figure 6: Daily CV of large producers’ revenues dependent on daily PV output 36

List of tables

Table 1: Risks for electricity consumers 10

Table 2: Risks for operating PV plants 13

Table 3: Risk profile of electricity prosumers 15

Table 4: Risks for large-scale electricity producers 19

Table 5: Scenarios for prosumer risk analysis 25

Table 6: Data type and source for cash flow analysis 27

Table 7: Descriptive statistics of variables used for cash flow calculation (2017) 28

Table 8: Data and sources for analysing the influence of prosumers on large producers 30

Table 9: Averages of cash flow descriptive statistics for prosumers 35

Table 10: Average daily CV of revenues of large producers [%] 36

List of acronyms

AGEB	Arbeitsgemeinschaft Energiebilanzen
BMWi	Bundesministerium für Wirtschaft und Energie (federal ministry for economic affairs and energy)
BR	business risk
CDF	cumulative distribution function
CF	cash flows
CV	coefficient of variation
DSO	distributed system operator
EBIT	earnings before interest and taxes
FCR	financial consumer risk
FIT	feed-in tariff
FL	fully liberalised
FR	financial risk
GW	gigawatt
kWp	kilowatt peak
n.a.	not applicable
PL	prosumer liberalised
PR	performance risk
PV	photovoltaic
Rem	remark
RES	renewable energy sources
RP	retail price
SCR	self-consumption ratio

TSO	transmission system operator
TWh	terawatt hour
WP	wholesale price

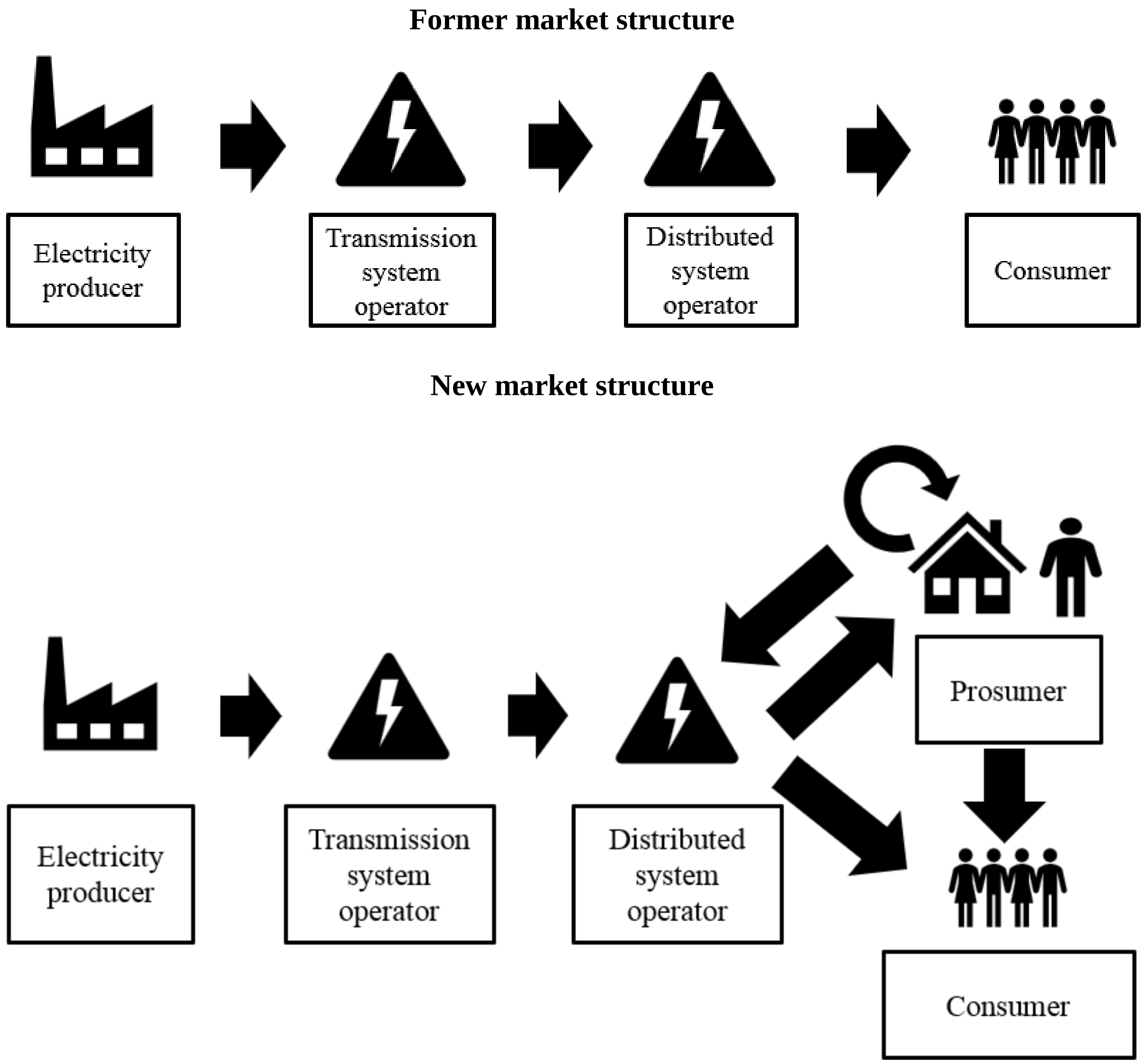
Summary

The thesis aimed to assess the risks an electricity prosumers face in Germany and their impact on the risk for large-scale electricity producers. The variability of returns for electricity prosumers is examined with a cash flow analysis at the example of residential solar power production for 2017. The data have been partly collected from 71 respondents of a survey as well as the German federal grid agency. Under current legal regulations for renewable energies, cash flows are almost stable per year. The abolishment of the support policies would result in an increase in volatility significantly from an average coefficient of variation of 6.72% to 59.51% under complete market liberalisation. The increased risk is mainly caused by the fact that solar radiation is low in winter and high in summer and electricity prices following the reverse pattern. Spearman's rank correlation coefficient of the daily coefficient of variation of large-producers' revenues and daily German solar power output is -0.2566 ($p<0.01$). That is, on days with high solar power output the revenues of large-producers were less risky in the observed time period (January 2015 until July 2018).

1 Introduction

Climate change and scarcity of fossil resources are two of the major societal challenges of the 21st century (Rathnayaka et al., 2014; Rogge et al., 2017). One of the main solutions to tackle the problems of emitting too much carbon dioxide and dependency on fossil resources is the transition towards renewable energy (Geller, 2003). During the past decades, a lot of politically enforced technological changes for electricity production occurred fostering the energy transition in the EU and in Germany in particular (Proskurina et al., 2016; BMWi, 2017a). Accordingly, large-scale electricity producers shut down their production facilities based on coal or nuclear energy (Löbbe & Jochum, 2016). The missing production capacity is replaced by renewable energy production sourced from wind, hydro, biomass and solar power. Within the course of the energy transition, the share of renewable electricity in Germany’s gross electricity consumption increased from 6.2% in 2000 to 31.7% in 2016 (BMWi, 2017b). In the same time, gross electricity production in Germany increased from 575 TWh to 648 TWh (i.e. by 12.70 percentage points), making the development even more impressive (AGEB, 2017).

Within the course of the energy transition the traditional market constitution is challenged (Rodríguez-Molina et al., 2014; Throndsen et al., 2017). Primary, the electricity market in Germany consists out of four different actors: electricity producers, transmission system operators (TSO), distributed system operators (DSO) and consumers (Rodríguez-Molina et al., 2014). Electricity producers generate power and sell it to the TSO. The TSO operates large grids to distribute high-voltage electricity over long distances. Afterwards, power is transformed into medium- and low-voltages and distributed to customers by DSO. However, the production systems for renewable energy also allow consumers of electricity to become a so called “electricity prosumer” (e.g. Nazari et al., 2014; Rodríguez-Molina et al., 2014; Jacobs, 2017). The term refers to a situation where a person/company/institution is producer and consumer of energy at the same time (Nazari et al., 2014; Rodríguez-Molina et al., 2014; Jacobs, 2017). The prosumer can make own decisions in terms of feeding power into the grid, purchasing power from the grid or consume his own produced electricity (Niknam et al., 2012; Velik & Nikolay, 2014; Stephens et al., 2015). Figure 1 illustrates the two different market constitutions where the arrows show the flow of electricity.



Source: Gross et al., 2013; Rodríguez-Molina et al., 2014; Velik & Nikolay, 2014

Figure 1: Comparison of electricity flow without and with prosumers

The German power generation sector is characterised by high market concentration and dominated by four large-scale producers: E.ON, RWE, Vattenfall and EnBW (Renn & Marshall, 2016; Tews, 2016). The concentration rate (CR_4)[1] has been constantly above 70 percent during the past years (Löbbe & Jochum, 2016; Renn & Marshall, 2016; Bundesnetzagentur & Bundeskartellamt, 2017). In the course of the energy transition, the picture is changing however. Within the renewable energy sector, private and institutional investors (except the "Big Four") account for 88% of the market (Salm, 2018). Concerning transmission of high voltage power, four players (TenneT, 50Hertz, Amprion and TransnetBW)

[1] The concentration rate measures the market share of the largest firms in a market. CR_n is the sum of the n largest firms' market shares (Demsetz, 1973).

operate the whole system (Nicolosi, 2010). Oppositely, end customers can choose between many providers as there are more than 800 regional and local utilities (DSO) (Löbbe & Jochum, 2016; Renn & Marshall, 2016).

The changing market structure does also imply changes for each actor and their exposure to risk. While literature dealing with single risks, such as price or production risks, affecting profitability of large-scale electricity production is extensive (e.g. Fraser, 2003; Deng & Oren, 2006; Kovacevic et al., 2013), to my knowledge, empiric evaluations for prosumers, i.e. small-scale decentralised electricity production incorporating self-consumption do not exist yet. Additionally, changes in risks for large-scale producers on electricity markets caused by the introduction of prosumption have neither been identified so far. Differences in the composition between as well as strength of factors influencing the variability of returns between large-scale and small-scale decentralised production are expected as it is the case in other sectors as well (Demsetz & Strahan, 1997). For instance, it has been argued that firm size affects the return on equity as larger firms face more systematic risk (Banz, 1981; Reinganum, 1981; Dijk, 2011).

The overall objective of this study is to identify and quantify the factors influencing the risk of returns as well as to analyse risk management possibilities from an electricity prosumer's perspective at the example of solar rooftop panels in Germany. Moreover, the influence of electricity prosumers in Germany on the variability of returns for the large electricity producers shall be examined from the electricity providers' point of view. These objectives result in three research questions to be answered:

1. What are peculiarities of risks and risk management for prosumers and large electricity producers?

2. Which risk factors influence the risk of returns of prosumers?

3. Does the emergence of electricity prosumers affect the volatility of returns of large electricity producers?

Contrary to other technologies, photovoltaic (PV) systems are extremely scalable, and therefore, allow every house- and landowner to engage in prosumption (Awerbuch, 2000; Schleicher-Tappeser, 2012). Therefore, the study analyses risks for PV prosumers. As open area installations are economically unattractive (Wozabal et al., 2013; Kelm et al., 2014; Dusonchet & Telaretti, 2015) only rooftop plants are considered.

The rest of the thesis is structured as follows: Chapter 2 reviews literature connected to the three research questions. In the beginning, the prosumer framework is introduced followed by a short section about defining risk qualitatively. Thereafter, risk profiles of prosumers are drawn and differentiated from a consumer’s and producer’s risk profile. It is then applied to the electricity prosumer for rooftop solar panels in the German case. Risk management possibilities are included here as well. Accordingly, this is done for large-scale electricity producers to create a model of risk factors, and changes in risk management due to increasing importance of prosumers. Chapter 3 contains materials and methods for the quantitative part. Thereafter, the results are presented (chapter 4). Chapter 5 discusses the results, concludes and shows potential for further research.

2 Literature review

In the following, a specification of the prosumer is given. Further, characteristics which are important for the risk profile are explained. Additionally, a short section deals with defining the term risk as it constitutes the core part of this study. A method for drawing a general prosumer risk profile is derived in section 2.3 as there is no such framework in the literature, yet, and applied to the electricity prosumer in 2.4.

2.1 Specifying the prosumer

The prosumer concept originates from Alvin Toffler (1980) and means that an individual is producer and consumer of a product or a service at the same time. In earlier times, when human beings solely consumed what they produced, e.g. making their own clothes being self-subsistent, “prosumption” was the only known form of economy (Kotler, 1986). Another typical example is a housewife whose services do also have a value (Throndsen et al., 2017). Mainly due to industrialization, production and consumption became separate functions in modern economies and the prosumer disappeared (Toffler, 1980). Nowadays, prosumers become more important again as companies e.g. engage customers in co-designing innovative products (Meuter et al., 2000; Magnusson, 2003; Izvercian & Potra, 2014). Other examples are self-service technologies, such as online banking (Considine & Cormican, 2017) or e-commerce (Morasch & Bandulet, 2003). Even though the prosumer has been introduced in literature almost 40 years ago, the framework receives rising attention since the shift towards renewable energy production started to which consumers substantially contribute in the past few years (Nazari et al., 2014; Rathnayaka et al., 2014; Büscher & Sumpf, 2015). The prosumption of electricity has also caused the EU to define the prosumer. However, they phrase it as an active customer but describe what the literature refers to as prosumer as shown before: “[…] a customer or a group jointly acting customers who consume, store or sell electricity generated on their premises, including through aggregators, or participate in demand response or energy efficiency schemes provided that these activities do not constitute their primary commercial or professional activitiy” (European Commission, 2016). That is, not only electricity production but also ancillary grid services are included in the definition which can be provided with the help of demand response programs (Ferruzzi et al., 2015a; Jacobs, 2017; Parag & Sovacool, 2016).

Prosumers carry both, characteristics of producers as well as consumers (Izvercian & Potra, 2014; Lavrijssen & Parra, 2017). Prosumption is frequently applied in innovation processes of companies but framed as open innovation (Chesbrough, 2003; Marais & Schutte, 2009; Izvercian et al., 2013). Customers provide ideas and co-design products with the company, thereby creating value. Idea sharing, designing a product or giving feedback on product designs does not require any investment of money for the prosumer. Thus, this type of prosumer carries more consumer than producer characteristics (Marais & Schutte, 2009; Lavrijssen & Parra, 2017). On the other hand, participating in demand response programmes in the electricity market or investing in an own PV power production is more of a producer behaviour (Lavrijssen & Parra, 2017). The differences between the types of prosumption will be used to draw a picture of the risk profiles after defining risk.

2.2 What is risk?

There are many different definitions of risk in literature. Generally, risk is often referred to as being negative, for instance the likelihood and degree of an adverse effect (Haimes, 2009). Kaplan & Garrick (1981) state that risk could be symbolically written as “risk = uncertainty + damage” (p. 12). This leads to another important term: uncertainty. Uncertainty can be described as a state of nature where different outcomes for an event are possible but the probabilities or the likelihood of the respective outcomes are unknown while risk implies knowledge about the probabilities (Piot-Lepetit & M’Barek, 2011). On the other hand, some authors use the terms risk and uncertainty interchangeably, i.e. there is no distinction between situations where probabilities can be assigned to outcomes or not, but all events that are not certain are risky and uncertain (Rothschild & Stiglitz, 1970; Chavas, 2004). This practice is adopted in this study. Note that despite to a variety of researchers using risk with a negative connotation, in this work risk and uncertainty refer to deviations from an expected outcome or event including positive as well as negative differences between expectations and reality.

2.3 Risk profile of prosumers

Prosumers’ risk profiles represent a combination of consumer and producer risks. As there is little literature on electricity prosumer risks in particular, this section illustrates a method how to derive a prosumer risk profile from consumer and producer risks extending the literature on prosumer risks.

Literature on consumer risks has a long history. Stern et al. (1977) break down overall perceived consumer risk into five types: financial, social-psychological, performance, physical and time. This framework has been adopted in various studies (e.g., Havlena & DeSarbo, 1991; Stone & Grønhaug, 1993; Mitchell, 1998). Financial risk refers to the potential loss of money when buying a product, e.g. due to overpricing (Jacoby & Kaplan, 1972). Exposure to performance risk means that the product does not work how it supposed to. Possible harm or injuries caused by a product are subsumed as physical risk. Further, in the socio-psychological dimension a consumer takes the risk that the product does not fit his/her self-image or concept, and the changing opinion of others induced by the purchase. Lastly, time risk describes the risk of wasting time when a product must be repaired, adjusted or replaced or not delivered in time (Roselius, 1971). The difference between time and performance risk is that performance refers to dissatisfaction or due to underperformance and time contains the resulting efforts. Though, some of the types are easily measurable such as time and money, others are not objectively calculatable, for instance socio-psychological risk (Mitchell, 1999). Anyway, consumers consider their perceived risk and base their purchase decision on subjective evaluations of those risks (Mitchell, 1999). Therefore, literature uses the concept of perceived consumer risk. Another perceived risk categorisation for product and service innovations only includes four types of consumer risks: economic, physical, functional and social (Ram & Sheth, 1989). The following categories are synonymously used as they are defined congruently to the first framework: financial and economic, physical and physical, and performance and functional. The second approach does not take into account psychological and time risk. Nowadays, studies dealing with consumer risks focus more on specific products and services, or technologies, such as self-service technologies (Considine & Cormican, 2017), electronic commerce (Morasch & Bandulet, 2003), customer co-design in online communities (Piller et al. 2005), genetically modified organisms applied in agriculture (e.g., Finucane & Holup, 2005; Klerck & Sweeney, 2007; Lu et al., 2016) or application of nanotechnology in food (Handford et al., 2014). This makes sketching a general state-of-the-art risk profile for consumers difficult because most studies concentrate on one type of risk and neglect the others. An example would be the case of nanotechnology in food where the main concern are health risks (i.e., physical) (Handford et al., 2014) and financial/economic risks are not mentioned. Contrary, online-banking does not involve any physical risks but very much of financial and performance risk perceived by customers (Lee, 2009). Hence, every product/service/technology requires its own risk evaluation concerning the strength of different risk types. In the rest of the thesis, financial, socio-psychological, performance, physical and time risk will be distinguished, i.e. used to categorise risks.

For producers, the two major blocks of risks are business and financial risk (Awerbuch, 2000; Hardaker et al., 2004; Horne & Wachowicz, 2008). Financial risk arises from the method of financing a firm and business risk includes all other risk factors occurring independently of the way of financing (Barges, 1962; Fraser, 2003; Hardaker et al., 2004). Thus, business risk includes production, input and output price, institutional/policy, and human/personal risk (Hardaker et al., 2004). A short notion before defining the single elements: there do also exist other categorisations of risk. Instead of business and financial risk as main types, often the distinction is made between market, liquidity, operational and credit risk (Christoffersen, 2003; Hillier et al., 2016). However, in the literature assessing risks of specific industries not a general framework is applied, and the existence of the single factors analysed, but adoptions to the specific research object are undertaken (e.g., Kaplan & Garrick, 1981; Amigun et al., 2011; Thun & Hoenig, 2011). In the investigated literature, the first framework is used for risk analyses of producers while the second rather appears in publications looking from corporate financial view. As this study takes the producer's and not a financial manager's perspective, it orients towards the first model, i.e. distinguishes between business risk and financial risk. In the following, single risks that influence the business risk are defined.

Production risk refers to all variations in output quantity that do not occur on purpose, e.g. yield variations due to uncertain weather conditions in agriculture (Hardaker et al., 2004). As input and output prices are usually uncertain, they are another source of risk for a producer (Wolak & Kolstad, 1991; Hardaker et al., 2004; Gross et al., 2013). Moreover, institutions and policy makers can represent a substantial risk factor (Erb et al., 1996; Butler & Joaquin, 1998; Hardaker et al., 2004). By introducing regulations and policies, possibilities and restrictions for companies in a market are given. For instance, introducing emission certificates for carbon dioxide was a negative risk to electricity producers using fossil resources (Blyth et al., 2007). On the other hand, changes in the regulatory framework of the German energy market imposing subsidies and guaranteed prices for renewable energy thereby enabling the RES to increase their contribution to the energy mix represents a positive risk for the renewable energy sector (Lipp, 2007). This example also illustrates the relationship between policy and financial risk. While financial risk looks at the form of financing in general including fluctuations of interest rates and sources of capital, policy risk affects financial risk e.g. by subsidies. Human or personal risks arise from human behaviour such as an inappropriate machine handling by an employee so that it must be replaced earlier than expected (Hardaker et al., 2004).

Apparently, producers' risk factors all connect to variability in costs and revenues either directly as it is the case for price risk or indirectly as it is the case for policy risk. The consumers' risk factors also imply a financial element but rather concentrate on the benefits from buying and consuming a product. An explanation might be the difference of the overall goal of consumers and producers. Neoclassic theory states that producers aim for profit maximisation while consumers want to maximise their perceived value of goods they consume, i.e. their utility (Varian, 2010).

The mentioned risk factors compose the risk profile of a prosumer. When prosumption is less characterised by entrepreneurial activities, the actor also faces rather the risks of a consumer. As shown above, using electronic commerce services (online shopping) is a form of prosumption. The risk profile changes but still consumer risks are dominating, for instance the risk of revealing private information or being faced with price discrimination for professional goods by the online shop provider (Morasch & Bandulet, 2003; Pavlou, 2003; Hsieh et al., 2005). Compared to traditional shopping, financial consumer risk will on the other hand also decrease to a certain extent as many different suppliers can be compared online so that the cheapest alternative can be chosen. Performance risk will increase as the product cannot be checked (visually and/or functionally) which can be important for search and experience goods (Hsieh et al., 2005). Note, that this issue is not relevant for highly standardised goods or services, e.g. paper (Alexander & Colgate, 1998). The time needed for commissioning a replacement or reparation order is reduced since the prosumer does not have to transport the product to a store, i.e. time risk is lower. Regarding physical and socio-psychological factors, changes are not expected. In addition, purchases are more prone to mistakes because a wrong click can easily happen. Moreover, it has shown that the majority of online-shoppers does not read the fine print so that they are likely to be ill-informed about the contractual agreements of their online-purchase (Bakos et al., 2014). That implies human/personal risk and belongs to producers. Hence, an implication of becoming a prosumer is the decrease in particular risk factors that a consumer typically is confronted while some risks might increase, and even new risks emerge (Liebrati & Giorgio, 2018).

2.4 Risks for electricity prosumers

This section derives a detailed risk profile for electricity prosumers at the example of rooftop solar panels. From now on, “prosumption” refers to small decentralised electricity production including self-consumption. As there is only little literature about the risks for electricity prosumers, the approach from section 2.3 is applied to add to publications on prosumer risks: First, risks for electricity consumers are shown. Secondly, the risks are displayed for operating a PV plant, i.e. producer risks. Lastly, both parts are combined to sketch the prosumers’ risk portfolio. Table 1 sums up the consumer risks that have been mentioned by authors. A cross indicates that the risk is mentioned. In the analysed literature, no quantitative assessment could be found but all have been qualitative. Except one author, all refer to financial risk as electricity prices are steadily increasing during the past years (e.g. Darghouth et al., 2014; Kästel & Gilroy-Scott, 2015; Biggar & Reeves, 2016). The second category identified frequently is performance risk as consumers are exposed to power outages (Schleicher-Tappeser, 2012; Juelsgaard, 2014; Kästel & Gilroy-Scott, 2015). Besides the presented two types, there are no other risks mentioned. A potential reason could be that electricity is taken as a matter of course (in developed countries) and is highly standardised[2]. Moreover, physical contact with electric power does not take place which eliminates all physical risk. Additional consumer risks are unlikely to occur when engaging in prosumption with a PV installation. Still, there should not be any physical or time risk. Regarding the socio-psychological dimension, Zoellner et al. (2008) and Kaldellis et al. (2013) do not find a considerable change in image when PV investments are undertaken, i.e. socio-psychological risk does not come into play.

Table 1: Risks for electricity consumers

Publication	Context	Financial	Performance	Physical	Socio-psychologic	Time
Biggar & Reeves, 2016	Australia	X				
Darghouth et al., 2014	United States	X				
Juelsgaard et al., 2014	Denmark		X			
Kästel & Gilroy-Scott, 2015	United Kingdom	X	X			
Lavrijssen & Parra, 2017	European Union	X				
Liebrati & Giorgio, 2018	United Kingdom	X	X			
Schleicher-Tappeser, 2012	Europe	X	X			
Thakur & Chakraborty, 2016	India	X				

The risks for producing power with a PV installation are displayed in the following. Table 2 shows the indicated risks in the literature. For producer risks, there are both qualitative as well

[2] A standardised commodity is a good that has uniform characteristics, i.e. all units are interchangeable (Black et al., 2009).

as quantitative analyses. However, it would be an erroneous impression to conclude that risks analysed quantitatively are more important as, for instance, policy risk is of great importance but hard to quantify (Holburn, 2012; Lüthi & Wüstenhagen, 2012; Gatzert & Vogl, 2016). Therefore, there is no distinction made in this section between qualitative and quantitative assessments. Besides policy risk, price, production and financial uncertainty appear often in publications. Regulations and laws regarding energy policy are typical to change frequently, especially during the last decade (e.g. Chassot et al., 2014; Holburn, 2012; Ottesen et al., 2016). Electricity prices are well-known to fluctuate strongly incurring output price risk (e.g. Dinica, 2006; Muñoz et al., 2009; Biondi & Moretto, 2015). But, by the renewable energy sources act renewable energy producers receive a guaranteed price, the feed-in tariff (FIT), for their electricity which is fixed for 20 years (Klessmann et al., 2008; Schleicher-Tappeser, 2012; Pyrgou et al., 2016). Hence, output price risk is completely eliminated in the German context. Input price risk does not come into play since marginal cost of a unit electricity produced are equal to zero (Klessmann et al., 2008; Schleicher-Tappeser, 2012; D'Alpaos et al., 2016). As PV power production depends on solar radiation which differs between days, weeks, months and even years, production risk lies in the very nature of solar panel operation (e.g. Mitchell et al., 2006; Schleicher-Tappeser, 2012; Ferruzzi et al., 2016). Fourth, uncertainty caused by different forms of financing such as bank loans are important as well (e.g. Dinica, 2006; Bhattacharya & Kojima, 2012; Ioannou et al., 2017). For instance, a project fails due to a lack of capital. Human risk on the other hand is mentioned only once, e.g. when the panels are installed wrongly (Ioannou et al., 2017). But, there are several types of risks that do not fit into the general categorisation: Technological uncertainty plays an important role for PV including unreliability of components, the chance of unexpected innovations so that the technology is outdated or decreasing yield over time (Arnold & Yildiz, 2015; Zeng et al., 2015; Ioannou et al., 2017). There is also the danger of damaging components during transport or construction (construction risk) (Komendantova et al., 2012; Arnold & Yildiz, 2015). Fluctuating demand is an issue for PV operators as well (Dinica, 2006; Bhattacharya & Kojima, 2012). Volume risk is more general and means that not all electricity can be sold on the market (Bhattarchaya & Kojima, 2012; Dóci & Gotchev, 2016). This is the case when more electricity is produced than demanded and vice versa. Both, volume and demand risk are not relevant in Germany since the purchase of renewable electricity is legally guaranteed (Klessmann et al., 2008).

If the producer of renewable electricity has to adjust his supply to the demand he/she is facing from DSO, he/she is exposed to balancing risk (Mitchell et al., 2006; Dóci & Gotchev, 2016). But, German law transfers balancing risk from renewable energy producers to TSO (Klessmann et al., 2008). Despite marginal cost of production being equal to zero, operation and maintenance costs occur that can fluctuate such as maintenance costs of general infrastructure (e.g. waste water disposal), inspection costs, cleaning panels and inverter maintenance costs (Krishnamurthy et al., 2012; Huenteler, 2014; Ramírez et al., 2017). Macroeconomic risks reflecting, e.g. swings in interest rates, were stated as well (Ondraczek et al., 2015). Ondraczek et al. (2015) state that it is not of relevance for developed countries in the context of renewable energies. Lastly, environmental risk describes potential damage to the environment by PV plants (Komendantova et al., 2012; Ioannou et al., 2017).

To sum up, table 3 shows the risk profile of electricity prosumers combining the results from table 1 and table 2. Earlier, it was indicated that the extent to which a prosumer is confronted with a risk can vary. For instance, the lower the self-consumption ratio (i.e. the share of self-consumed power in total power production) the stronger producer risks might be incurred.

Table 2: Risks for operating PV plants

Publication	Context	Policy	Price	Human	Production	Financial	Other risks
Alessandrini et al., 2015	Italy				X		
Arnold & Yildiz, 2015	Germany	X	X		X	X	Construction, Technical, Operational
Bhattarchaya & Kojima, 2012	Japan	X	X			X	Demand, Volume
Biondi & Moretto, 2015	Italy		X				
Büscher & Sumpf, 2015	Germany	X	X				
Chassot et al., 2014	United States & Europe	X					
Darghouth et al., 2014	United States		X				
Dinica, 2006	European Union		X			X	Demand
Dóci & Gotchev, 2016	Germany & The Netherlands		X				Balancing, Volume
Esther & Kumar, 2016	Not specified	X					
Ferruzzi et al., 2016	Italy				X		
Gatzert & Vogl, 2016	France & Germany	X					
Gross et al., 2013	Europe				X		
Hernández-Moro & Martínez-Duart, 2013	Worldwide				X		
Hirth, 2013	Europe				X		
Holburn, 2012	Canada & United States	X					
Huenteler, 2014	Developing countries		X				Operation cost

Ioannou et al., 2017	Worldwide	X	X	X	X	X	Technological, environmental
Komendantova et al., 2012	North Africa	X	X		X	X	Environmental, construction
Krishnamurthy et al., 2012	India						Operation cost
Liebrati & Giorgio, 2018	United Kingdom		X		X		Demand
Mitchell et al., 2006	England, Wales & Germany		X		X		Balancing
Muñoz et al., 2009	Spain	X	X				
Ondraczek et al., 2015	Worldwide	X				X	Macroeconomic
Ottesen et al., 2016	Norway	X			X		
Polzin et al., 2015	OECD countries	X					
Rahi et al., 2017	Not specified		X				
Schleicher-Tappeser, 2012	European Union	X			X		
Zeng et al., 2015	United States				X		Technical, Cost

Table 3: Risk profile of electricity prosumers

Risk	Traditionally belongs to	Comment
Financial	Consumer	Reduced (compared to pure consumption)
Performance	Consumer	Reduced (compared to pure consumption)
Policy	Producer	
Electricity price	Producer	Legally eliminated in Germany
Input price	Producer	Not relevant due to no inputs used
Production	Producer	Legally eliminated in Germany
Financial	Producer	Not relevant due to fixed interest rate
Demand	Producer	Legally eliminated in Germany
Cost	Producer	
Balancing	Producer	Legally eliminated in Germany
Human	Producer	
Macroeconomic	Producer	Only relevant in developing countries
Technological	Producer	
Environmental	Producer	Not carried by prosumers

2.5 Risk management possibilities for PV prosumers

As shown, there are several risks involved when becoming an electricity prosumer. This section presents different measures to avoid, mitigate and transfer the identified risks from the prosumer's point of view.

To mitigate the probability of policy changes, prosumers can form organisations which engage in lobbying activities and try to influence politicians in the desired direction (Holburn, 2012; Gatzert & Kosub, 2016). Additionally, one can create political value with the business, i.e. implementing a policy which is not desired by the prosumer or imposing harm to his/her business would affect the public opinion of the politicians negatively (Holburn, 2012; Gatzert & Kosub, 2016). An example from a different sector is the generation of jobs in a small community by few and big companies. A policy measure that affects them negatively is likely to cost jobs which in turn impairs public opinion towards policy makers. Thus, the firms hiring many people in rather rural environments create political value to policy makers. Third, contracting can help to reduce policy risk to a certain extent (Holburn, 2012; Gatzert & Kosub, 2016). That is for instance, agreements on prices with utilities laid down in contracts creates independence from subsidiary systems and changes in the latter.

To smoothen the supply profile of electricity, PV operators can install storage capacities (Merei et al., 2016; Tews, 2016; Liu et al., 2018). They store excess electricity at times when their demand is fully satisfied by the PV plant and use it when production by solar panels is not sufficient to cover own demand. The intuition behind this are price differences between FIT rate and higher retail prices (Oberst & Madlener, 2014; Pyrgou et al., 2016; Tews, 2016). Feeding energy into the public grid is reimbursed at the FIT rate while for self-consumption retail prices must be used. Of course, that does not decrease variability in production. However, it allows to improve utilisation of production and decreases volatility of supply.

For financial risk, an investor can vary the form of finance, especially the debt to equity ratio while an increase of the ratio goes hand in hand with an increase in financial risk (Hardaker et al., 2004; Hillier et al., 2016). Thus, to mitigate financial risk, investments would c.p. be financed with more equity. In case of Germany, interest rate risk caused by fluctuating interest rates (Seubert & Weber, 2013) does not come into play as interest rates on loans are usually fixed for ten years (Brückner & Lücke, 2004). Moreover, interest rates remain on a low level since several years so that interest rate risk as a part of financial risk is less severe (Ondraczek et al., 2015). In addition, to avoid a lack of sufficient access to capital, contingency plans for "what-if" scenarios are useful (Gatzert & Kosub, 2016).

Usually, insurances or maintenance contracts are used to decrease volatility of operating cost (Branker et al., 2011). Besides, no risk management tool for cost risk could be found in the literature.

2.6 Risks for large-scale electricity producers

This section shows the risk factors that are relevant for large-scale electricity producers which are RWE, E.ON, Vattenfall and EnBW mainly operating plants based on fossil energy sources such as oil, gas, coal as well as nuclear energy.

Almost all publications dealing with risks for electricity producers mention input price (e.g. Awerbuch & Sauter, 2006; Branker et al., 2011; Thakur & Chakraborty, 2016) as well as output price risk (e.g. Eichhorn, 2013; Paraschiv, 2013; Rintamäki et al., 2017). Policy (e.g. Blyth et al., 2007; Fuss et al., 2008; Holburn & Zelner, 2010) and financial risk (Gross et al., 2010; Pineda & Conejo, 2012; Farfan & Breyer, 2017) are both important considering the number of researchers taking it into account. Human risk does not play a role in the literature. Production risk is mentioned only in two studies (Gross et al., 2013; Wozabal et al., 2013). In addition, fluctuations in costs for emitting greenhouse gases has been pointed out to be a major risk in electricity production based on fossil resources (e.g. Fuss et al., 2008; Daskalakis & Markellos, 2009; Park et al., 2011). Besides, maintenance risk (Bhattacharya & Kojima, 2012; Gross et al., 2010; Gross et al., 2013) and demand risk, i.e. volatility (Daskalakis & Markellos, 2009; Thakur & Chakraborty, 2016) are considered. Short-term fluctuations in demand are of special importance to large-scale producers since they must balance them out with flexible production plants, e.g. gas turbines which produce at cost being twice as high as for brown coal (Kost et al., 2018). Hence, producers are rather concerned with short-term fluctuations in demand which have to be balanced with expensive flexibility. The result of the literature research is summed up in table 4. Again, there is not distinction between qualitative and quantitative analyses for the beforehand already mentioned reason.

As table 4 shows, prosumers have not been identified by previous literature as a risk factor for large-scale producers. But, various authors report that intermittent renewable energy production impacts both electricity price as well as its volatility, and thereby the fluctuations in profitability of conventional power plants (Green & Vasilakos, 2011; Paraschiv et al., 2014; Rintamäki et al., 2017). Generally, solar power and wind power are considered to decrease electricity prices (Paraschiv et al., 2014). Moreover, this impact is stable during peak hours for solar power. Therefore, PV electricity generation is likely to dampen price volatility in the short-term (Rintamäki et al., 2017). Some researchers argue that incorporation of RES in the energy market increases price volatility because range and volatility of residual demand increases and translate into price fluctuations (Wozabal et al., 2013).[3] On the other hand, researchers propose that wind power destabilises electricity prices (Jónsson et al., 2010; Ketterer, 2014). In addition to the general price decrease caused by RES, limited predictability of RES leads to higher cost of conventional generation due to the required flexibility of the plants (Klessmann et al., 2008; Schleicher-Tappeser, 2012; Ueckerdt et al., 2013). In times of low or even negative prices, producers face the decision to even shut down plants with low flexibility such as coal or nuclear plants (Gross et al., 2013; Paraschiv, 2013). Their shutdown is in turn connected with high cost and poses the risk of component failure (Gross et al., 2013). Hence, prosumers using renewable electricity production technologies are likely to impact large producers' volatility especially in the short-term. However, this impact has not been analysed, yet.

[3] Residual demand refers to the demand that is not covered by controllable power plants. Before the large introduction of RES, residual demand simply stemmed from forecast errors in demand (Wozabal et al., 2013).

Table 4: Risks for large-scale electricity producers

Publication	Context	Policy	Price	Human	Production	Financial	Other
Awerbuch & Sauter, 2006	European Union & United States		X				
Bhattacharya & Kojima, 2012	Japan		X				Emission costs, maintenance
Blyth et al., 2007	Worldwide	X					
Branker et al., 2011	Worldwide		X				
Daskalakis & Markellos, 2009	France, Germany & Scandinavia		X				Emission costs, demand
Eichhorn, 2013	Austria & Germany		X				Emission costs
Farfan & Breyer, 2017	Worldwide					X	
Fuss et al., 2008	Germany	X	X				Emission costs
Fuss et al., 2009	Not specified	X					
Gross et al., 2010	United Kingdom		X			X	Emission costs
Gross et al., 2013	Europe		X		X		
Holburn & Zelner, 2010	Worldwide	X					
Klessmann et al., 2008	Germany, Spain & United Kingdom		X				
Larsen & Bunn, 1999	United Kingdom	X					
Paraschiv, 2013	Germany		X				
Paraschiv et al., 2014	Germany		X				
Park et al., 2011	United States		X				Emission costs

Pineda & Conejo, 2012	Germany	X		X	
Rinamäki et al., 2017	Denmark & Germany	X			
Thakur & Chakraborty, 2016	India	X			Demand
Thollander et al., 2010	Worldwide	X			
Vehviläinen & Keppo, 2003	Scandinavia	X		X	
Werner & Scholtens, 2017	Germany	X			
Wozabal et al., 2013	Germany & United States	X	X		Emission costs

2.7 Risk management for large electricity producers

The risk management for large-scale electricity producers differs from the ones of prosumers, also due to their scale. More flexible power plants allow to increase flexibility and thereby to smoothen electricity price structure (Eichhorn, 2013; Gross et al., 2013; Hach & Spinler, 2016). Besides, input sourcing as well as maintenance planning can decrease input price and maintenance cost risk respectively (Eichhorn, 2013).

One of the most commonplace instruments to reduce risk is diversification of a business (Markowitz, 1959; Elton & Gruber, 1977; Amit & Livnat, 1988). This is also the case for electricity production (Augutis et al., 2015; Chalvatzis & Rubel, 2015; Kileber & Parente, 2015). That is, to invest in different electricity generating technologies and to not only focus on one or two.

In addition, energy derivatives such as forwards, futures and options are common instruments to hedge electricity price risk (Stoft, 2002; Willems & Morbee, 2010; Pineda & Conejo, 2012). There does also not appear counterparty risk for buying or selling futures and options as they are usually traded on an exchange representing an intermediary party (Burger et al., 2007; Gross et al., 2013). Forwards are very similar to futures; however, they involve counterparty risk as they are traded bilaterally between power market actors (Gross et al., 2013).

2.8 Concluding remarks

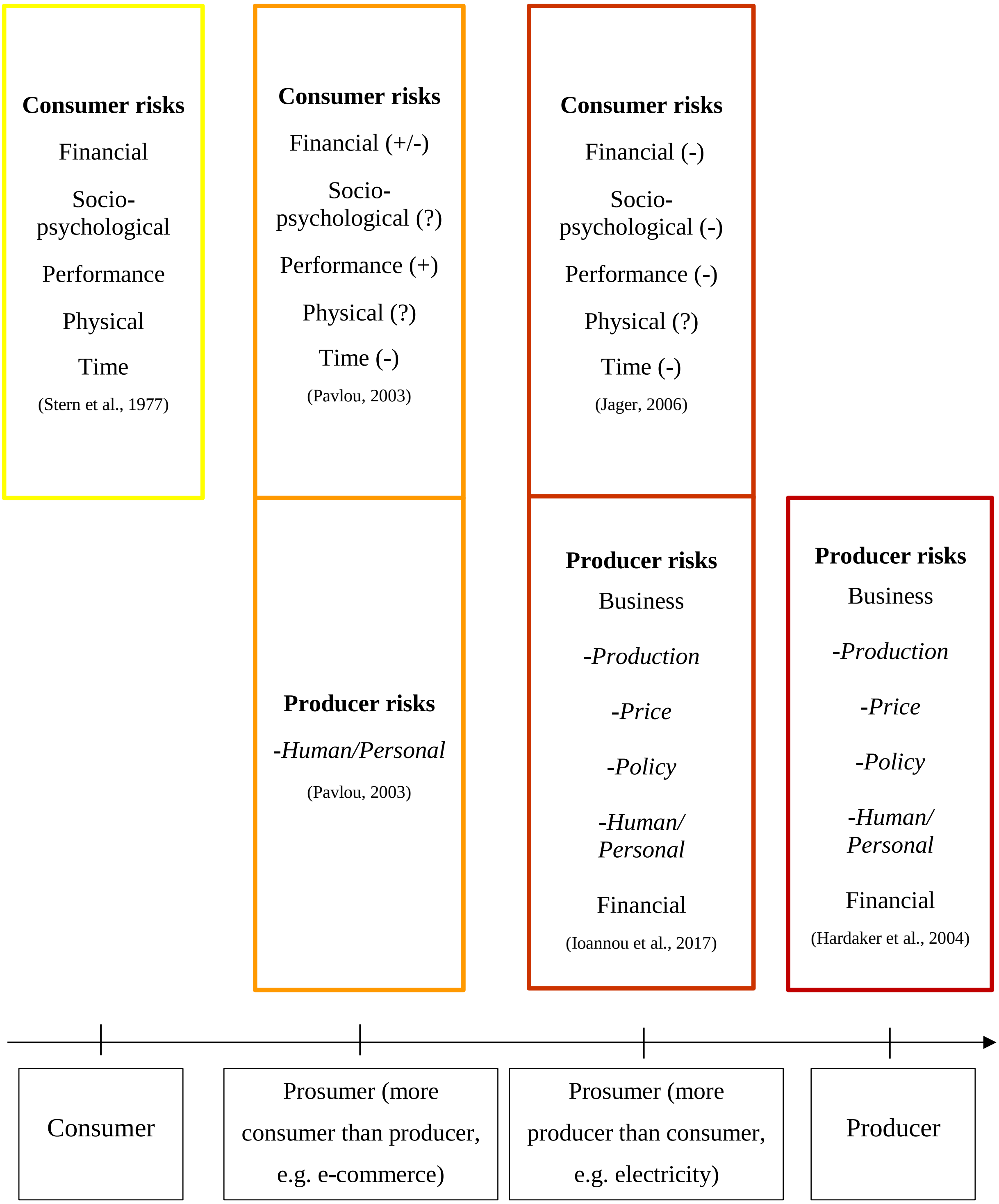
The literature research reveals that the electricity prosumer case is distinct from other types of prosumption for several reasons. Contrary to other cases, for instance farmers consuming their own apples, the self-consumption ratio (approximately 35%) for electricity prosumers is much higher (Schleicher-Tappeser, 2012). Contrary to customer co-design cases for instance, electricity prosumers carry entrepreneurial characteristics and corresponding risks. Moreover, power cannot be stored for a longer period of time without substantial losses (Vehviläinen & Keppo, 2003). That also leads to a need of matching supply and demand at any point of time due to the latter being highly inelastic in the short-term (Paraschiv, 2013) and absence of sufficient storage capacities (Klessmann et al., 2008). Besides, the RES act with its various updates implies a strict regulatory environment leading to a unique infrastructure of the German market with legally guaranteed access for every prosumer (Löbbe & Jochum, 2016).

As prosumers are both consumer and producer at the same time, there are also risks of consumers and producers involved. The literature research reveals that a prosumer faces mainly financial and performance risk from the consumer side and policy, production quantity, technology and cost risk for the producer side. Engaging in prosumption includes consumer and producer characteristics, and consequently involves consumer and producer risks. The derivation of a prosumer risk profile is illustrated in figure 2.

There are several studies analysing risks of investments in solar panel plants which look at the problem from a producer's or investor's point of view. However, an assessment of the presented risks from the prosumer perspective has not been conducted yet which is the first scope of this study.

Moreover, the risk portfolio of large producers has been subject of research in the past. It is acknowledged that RES influence size and volatility of electricity prices. As prosumers solely use renewable energy production technologies, they will impact other market players. How risks for large power producers in the German market are changed in particular by prosumers has not been investigated so far and is therefore assessed in this thesis.

Comparing the overall risk profiles of large producers and prosumers, it is remarkable that mostly uncertainty concerning input and power prices as well as developments on financial markets are mentioned in the literature for large producers. On the other hand, prosumers seem to face mostly policy risk plus financial consumer and performance risk. The differences are mainly due to choice of production facilities. By running extremely reliable conventional power plants using fossil resources, producers are exposed to strong input price fluctuations. Further, operating large production facilities is capital intensive leading to high financial risk. For prosumers, the EEG eliminates all price risk as well as production risk during the year. A change in law and regulations is, according to previous studies, the biggest risk for them.



Rem.: Starting point is always the consumer (left hand side), moving towards a pure producer (right hand side) with e-commerce prosumer (few producer characteristics and risks; light orange box) and electricity prosumer (many producer characteristics and risks; dark orange box); Changes of consumer risks by becoming prosumer compared to a pure consumer: + = increasing risk; - = decrease in risk; ? = no statement can be made

Figure 2: Comparison of risk profile derivation of e-commerce and electricity prosumer

3 Methodology and data

The chapter presents the methodology for the analysis of electricity prosumer risks and their influence on producer risk as well as the sources of the required data.

3.1 Prosumer risk analysis

A popular method to analyse the risk of running a PV system is cash flow analysis (e.g. Bianchini et al., 2016; Lang et al., 2016; Tse et al., 2016). Contrary to previous studies however, in addition to producer risks also decreases in consumer risks are included in the analysis which comprise financial consumer risk and performance risk. To incorporate these, the costs of a power outage and saved electricity expenses are added to operating cash flows (CF) obtained from the plant (equation (1)):

$$CF_{i,n} = ((FIQ_n \cdot FIT_n + SC_n \cdot RP_n)/12 + T_{PO,i,n} \cdot C_{PO} - C_{OM,i,n})/S_n \quad (1)$$

where $CF_{i,n}$ is the cash flow in month i for prosumer n [€/kWp], FIQ_n is the quantity of power fed into the grid per year for prosumer n [kWh], FIT_n is the FIT rate for prosumer n [€/kWh], SC_n is the amount of electricity produced and consumed by the prosumer per year for prosumer n [kWh], RP_n denotes the retail price for prosumer n [€/kWh], $T_{PO,i,n}$ is the amount of power outage at the location of the installation in month i for prosumer n [minutes], C_{PO} are the costs of power outage [€/minute], $C_{OM,i,n}$ represents the operating and maintenance costs in month i for prosumer n [€] and S_n is the size of the plant of prosumer n [kWp]. Equation 1 contains the standard cash inflow which is FIQ times FIT. Since saved electricity expenses (SC · RP) are included the cash flow CF does not represent an actual flow of cash. However, it is commonplace to add costs that are avoided because of an investment in the investment analysis (Hillier et al., 2016). The saved electricity expenses account for financial consumer risk. The same principle holds for the costs of a power outage to incorporate performance risk. Operating and maintenance cost represent uncertainty of costs. Moreover, technological and human risk result in additional cost which is also captured by C_{OM}.

This prosumer CF per kWp and month is the final variable whose volatility is analysed to examine the prosumer risk (Munoz et al., 2009; Allan et al., 2011; Ioannou et al., 2017). The measures used are standard deviation (Markowitz, 1959; Rothschild & Stiglitz, 1970; Huang, 2008) and the coefficient of variation (CV). The latter is calculated by dividing the standard deviation of a variable by its mean (equation 2) and has the advantage of being a relative measure (Gabriel & Baker, 1980; Horne & Wachowicz, 2008; Mey et al., 2014):

$$CV_{CF,n} = \sigma_{CF,n} / \mu_{CF,n} \tag{2}$$

where $CV_{CF,n}$ is the coefficient of variation of cash flows for prosumer n, $\sigma_{CF,n}$ is the standard deviation of monthly cash flows for prosumer n [€/kWp] and $\mu_{CF,n}$ denotes the mean of the monthly cash flows for prosumer n. The risk factors derived from literature for a prosumer have been confirmed during an interview with a prosumer to occur in practice (Appendix I).

Lastly, to account for political uncertainty, a scenario analysis is conducted to show the effect of the most likely policy changes on the risk for prosumers which is a common tool to include policy risk in analyses (Cai et al., 2007; Kannan, 2009; Thiel et al., 2010). The general trend in the German political debate goes in the direction of liberalising the market and abolishing political support for renewable energies. This is not only announced by Peter Altmaier, minister for economic affairs (Witsch, 2018), but can be observed. FIT rates have been steadily decreasing during the past years due to the reduction of governmental support (Pyrgou et al., 2016). That is, a plant of the same size installed in 2010 receives a much larger FIT than a plant installed in 2014. The scenarios imply exposure to price fluctuations for electricity at wholesale level (WP) and retail level (RP) as well as production risk, i.e. a prosumer is paid for the actual amount of electricity sold according to the load profile. WP is the price that TSO also pay to large producers at the spot market. RP is the price that consumers pay to DSO to purchase power from the grid. An overview of the scenarios can be found in table 5.

Table 5: Scenarios for prosumer risk analysis

Scenario	Wholesale price	Retail price	Payments according to load profile
Baseline	no	fixed	no
Prosumer liberalised	yes	fixed	yes
Fully liberalised	yes	fluctuating	yes

The baseline scenario describes the current state. WP and payments according to the load profile, i.e. actual production would be the first step to expose solar panel operators to market risks which is called the prosumer liberalised scenario as consumers are still not included here. Specifically, prosumers would then receive the same price for their electricity as large power providers like the big four. While the big four trade with TSO, prosumers sell their power to DSO (figure 1). Thus, prosumers get paid the monthly sum of hourly WP times the electricity they fed into the grid in the respective hour.

Based on the assumptions of PL, the cash flow calculation must be slightly adjusted to:

$$CF_{i,n} = ((\sum_{t=1}^{24} \sum_{d=1}^{m} FIQ_{t,d,i,n} \cdot WP_{t,d,i} + SC_{t,d,i,n} \cdot RP_{n}) + T_{PO,i,n} \cdot C_{PO} - C_{OM,i,n})/S_{n} \quad (3)$$

where $FIQ_{t,d,i,n}$ denotes the feed-in quantity of prosumer n at hour t on day d in month i [kWh], $WP_{t,d,i}$ is the wholesale electricity price at hour t on day d in month I [€/kWh], $SC_{t,d,i,n}$ is the self-consumed electricity by prosumer n at hour t on day in month m [kWh] and m depicts the last day of the respective month.

The last scenario for the future to come is the fully liberalised market scenario. Besides producers of renewable energy, also energy consumers might be confronted with price signals in the next years which is included by a fluctuating retail price. According to Esther & Kumar (2016), Aghajani et al. (2017) and Strbac (2018) transmitting price fluctuations to consumers is likely in the future to smoothen the load curve on the market. In times of high prices, consumers are supposed to react with a reduction in demand and vice versa. Thereby, the load curve is expected to become flatter and power can be produced at lower cost as the flexible plants producing more expensively will be less needed. For the FL scenario the cash flow calculation changes to:

$$CF_{i,n} = ((\sum_{t=1}^{24} \sum_{d=1}^{m} FIQ_{t,d,i,n} \cdot WP_{t,d,i} + SC_{t,d,i,n} \cdot RP_{t,d,i,n}) + T_{PO,i,n} \cdot C_{PO} - C_{OM,i,n})/S_{n} \quad (4)$$

where $RP_{t,d,i,n}$ is the hypothetical retail price of prosumer n at hour t on day d in month i [€/kWh].

For scenarios including payment according to the actual load profile, it is assumed that the PV output quantity follows the same structure as the solar radiation at the location of the installation (Liu et al., 2018). There are other factors affecting solar output such as temperature. But, it was found that the major determinant is solar radiation and focussing on that parameter only leads to small errors (Raza et al., 2016). The actual output could be measured and communicated in practice using smart metering technology (Kabalci, 2016). For the fully liberalised scenario, it is insufficient to transfer price changes from wholesale to retail level in absolute terms since taxes and other duties would be ignored (Bundesnetzagentur, 2018b). Therefore, fluctuations are assumed to be transmitted proportionally to consumers. That is, an increase of the WP of 10 percentage points will lead to an increase of the RP of 10 percentage points. Besides, it is assumed that electricity cannot be stored in any scenario as at the end of 2017 just 85,000 (280 MW) out of 1,600,000 (41.71 GW) installations were combined with a storage device, i.e. 5% of the number of installations (0.67% of installed capacity) (Figgener et al., 2018; Wirth, 2018).

Table 6: Data type and source for cash flow analysis

Data	Source	Used in scenario
Electricity feed-in (FIQ)	Survey	All
Feed-in tariff (FIT)	Bundesnetzagnetur, 2018a	Baseline
Self-consumption (SC)	Survey	All
Retail price (RP)	Survey	All
Time of power outage (T_{PO})	Bundesnetzagentur, 2018c	All
Costs of power outage (C_{PO})	Nooij et al., 2007; Carlsson & Martinsson, 2008; Reichl et al., 2017	All
Operation & maintenance costs (C_{OM})	Survey	All
Plant size (S)	Survey	All
Solar radiation	NASA, 2018	Prosumer & Fully liberalised
Wholesale prices (WP)	SMARD, 2018	Prosumer & Fully liberalised
Standard load profile	BDEW, 2018	Prosumer & Fully liberalised

Table 6 shows data with the respective sources of the variables. A telephone survey was used to approach prosumers all over Germany. Their postal addresses are available on the website of the federal grid agency (Bundesnetzagentur, 2018a). The phone numbers could then be found in a directory (Das Örtliche, 2018). The sample is randomly selected. Due to the fact that only postal addresses of plants with a capacity of at least 30 kWp are published, snowball sampling is applied to also include smaller plants. Regarding cost of power outages, Reichl et al. (2017) state that the loss per person affected by a power outage per hour is €0.30 in Austria while Nooij et al. (2007) calculate an average of €2.67 per person in the Netherlands and Carlsson & Martinsson (2008) measure €0.58 per person and hour in Sweden. The difference of more than two Euros stems from utilization of different estimation methods. As the differences are significant, the analysis is carried out once with each price. The amount of time that a power outage occurred is available from 2008-2016 with exact point of time and duration including the number of people affected (Bundesnetzagentur, 2018c). The observations cannot be traced back to a specific location but are aggregated on national level and only annual averages for the federal states can be found. It is assumed that all locations in the same federal state are exposed to the same amount of time concerning power outages. To distribute consumption, standard load profiles in Germany are used (BDEW, 2018). The load profile is illustrated in figure A.2. The telephone survey has been conducted from 1st of July until the 15th of August 2018. A total of 428 solar panel operators has been approached of which 71 participated. The data of the survey are given Appendix II (tables A.1 and A.2).

Table 7: Descriptive statistics of variables used for cash flow calculation (2017)

Variable	Mean	Standard deviation	Minimum	Maximum
Electricity feed-in[a] [kWh]	31,783.53	61,093.74	125.44	412,277.00
Feed-in tariff[b] [€-cent/kWh]	12.74	1.64	10.71	18.32
Self-consumption[a] [kWh]	13,904.26	22,853.60	1,018.24	130,182.25
Retail price[a] [€-cent/kWh]	28.72	1.86	21.10	31.00
Power outage[c] [minutes]	11.28	3.47	8.28	26.12
Costs[a] [€/year]	232.14	207.33	0.00	1,099.00
Plant size[a] [kWp]	49.91	82.75	4.16	540.00
Wholesale price[d] [€-cents/kWh]	3.42	1.77	-8.30	16.35

Sources: a = Survey; b = Bundesnetzagentur, 2018a; c = Bundesnetzagentur, 2018c; d = SMARD, 2018

3.2 Influence of prosumers on large producers

Whether prosumers have an influence on the short-term volatility of returns of large-scale producers is the third scope of the thesis. To test for an effect of prosumers on large producers' profit volatility, necessary cost data and exact production quantities of respective power plants are missing. Therefore, only statements about revenues are possible.

Wozabal et al. (2013) argue that the volatility of demand for large producers' electricity increases and translates further into stronger wholesale price fluctuations with growing implementation of renewable power production. Oppositely, Rintamäki et al. (2017) state that PV production has a decreasing effect on the volatility of wholesale electricity prices. Also contrary to Wozabal et al. (2013), I argue that the volatility of demand decreases by increased PV power production. Since PV output follows the same pattern as total power consumption, the volatility of demand for large producers' power decreases with higher PV production (figure A.8 and figure A.9). Decreasing volatility of prices and decreasing volatility of demand faced by large producers with increasing PV production leads to the hypothesis:

H: Increasing output by PV prosumers correlates negatively with the variability of revenues of large producers.

The daily CV of large producers' hourly revenues is used as it allows cross comparison between all points in time.

The formula for estimating the revenues is given in equation 5:

$$R_{t,d} = P_{t,d} \cdot (D_{t,d} - Q_{t,d,PV}) \tag{5}$$

where $R_{t,d}$ denotes the revenue in hour t on day d [€], $P_{t,d}$ the wholesale electricity price in hour t on day d [€/MWh], $D_{t,d}$ the total electricity consumption in hour t on day d [MWh] and $Q_{t,d,PV}$ the PV production in hour t on day d [MWh]. PV production represents the prosumer activity which includes both: self-consumed electricity and power fed into the grid. Both must be subtracted from total consumption to obtain market demand which large producers face. The intuition behind that is the legally guaranteed purchase of the prosumer power by TSO. Hence, even though the feed-in is not immediately consumed by prosumers, it must be subtracted from total consumption to arrive at the market demand for large producers (Kelm et al., 2014).

The next step is the estimation of the CV for each day which is:

$$CV_d(R_{t,d}) = \sigma_d(R_{t,d})/\mu_d(R_{t,d}) \tag{6}$$

where $CV_d(R_{t,d})$ is the coefficient of variation of hourly revenues on day d, $\sigma_d(R_{t,d})$ the standard deviation of hourly revenues on day d [€] and $\mu_d(R_{t,d})$ the mean of hourly revenues on day d [€].

Finally, the correlation analysis is conducted. Based on a visual analysis, the CV of revenues and PV production are not following a normal distribution (see Appendix III); hence, Spearman's rank correlation coefficient is used (Spearman, 1987; Artusi et al., 2002). The coefficient is calculated as follows:

$$r_s = Cov(rg_{CV,d}, rg_{PV,d})/(\sigma(rg_{CV,d}) \cdot \sigma(rg_{PV,d})) \tag{7}$$

where r_s is the Spearman's rank correlation coefficient, rg_{CV} is the rank of the coefficient of variation of large producers revenues on day d, rg_{PV} is the rank of PV production on day d, Cov is the covariance and σ denotes the standard deviation. The ranks are created by assigning a number from one up to d to the CV on each day of the observation period. One is assigned to the lowest CV in the period, two is assigned to the second lowest in the period and so on until the largest CV is reached. The same is done for PV. Thereafter, the correlation of the ranks of

CV and PV is calculated according to (7). Since the ranks are used instead of the absolute values, it does not assume a linear but a monotonic relationship. r_s takes on values between -1 and 1 while -1 indicates a perfect negative monotonic relationship between CV and PV production and 1 indicates a perfect positive monotonic relationship between CV and PV production. Student's t is applied to test the significance of r_s (Zar, 1972).

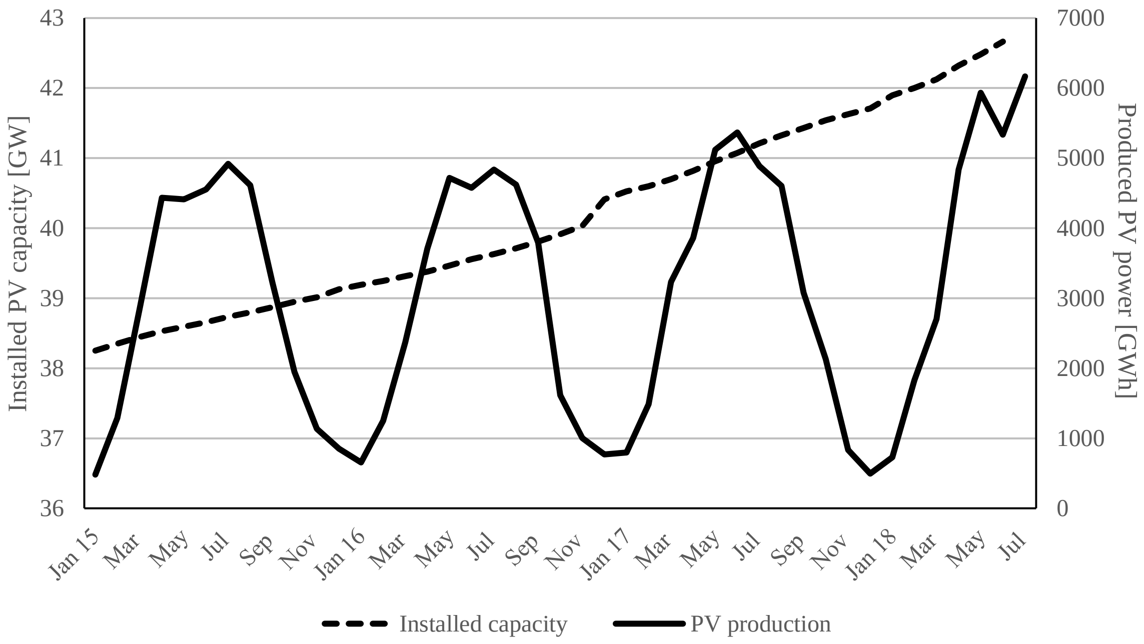
The hourly data are available from 6th of January 2015 until the 31st of July 2018. Even though data can be found on a longer time horizon, SMARD (2018) is chosen as the source due to its high time resolution. High time resolution allows to capture volatility in very short time steps.

Table 8: Data and sources for analysing the influence of prosumers on large producers

Data	Source
Wholesale electricity prices	SMARD, 2018
PV production	SMARD, 2018
Power consumption	SMARD, 2018

The descriptive statistics of the variables for the analysis of large producers' revenue volatility are given in table A.3. The data set contains 31,272 points, i.e. 24 on each of the 1,303 days in the observation period. Raw data regarding newly installed, total installed PV capacity and production per month over time in Germany are given in table A.4. Moreover they are illustrated in figure 3. Installed capacity increased by almost 12 percentage points from beginning of 2015 (38.13 GW) until June 2018 (42.66). But, power produced by solar panels does not show a similar movement over time except 2018 where a yield of more than 6,000 GWh was exceeded compared to approximately 5,400 GWh in June 2017. This can be explained by slightly lower solar irradiation in 2016 and 2017 compared to 2015 and the first half year of 2018 (NASA, 2018). Accordingly, total PV output (Q) in 2015 was 34.72 TWh, in 2016 33.91 TWh and in 2017 35.88 TWh. The production curve clearly shows a seasonal pattern with lowest yields in January and highest yields during the summer months.

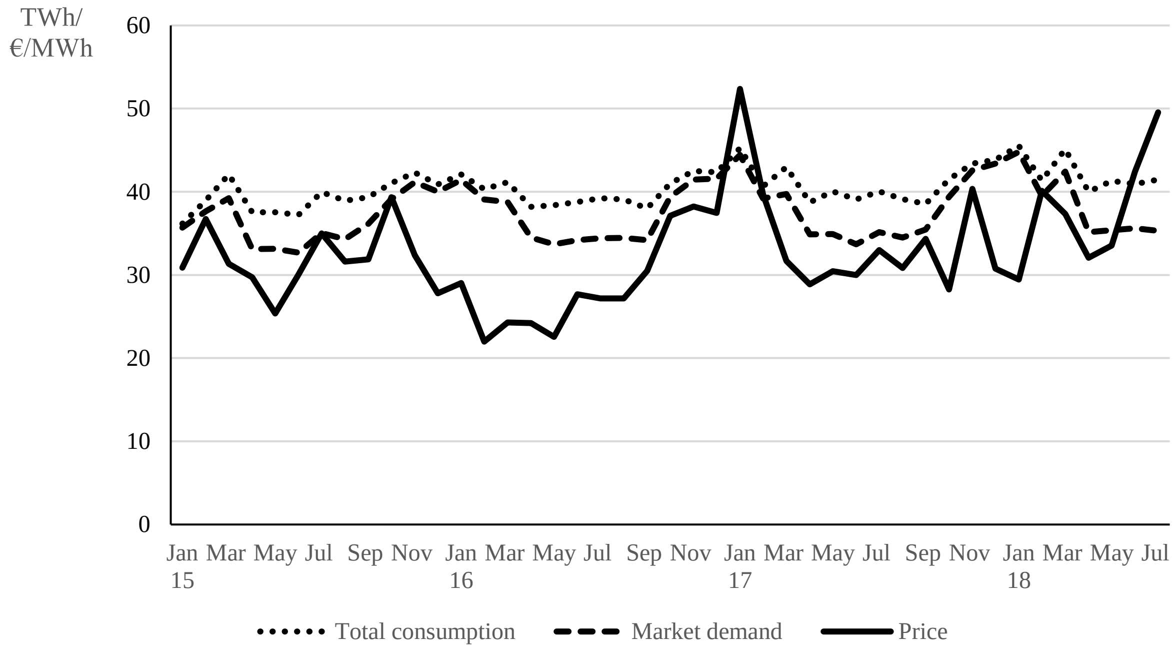
Annual total electricity consumption (D) and market demand ($D-Q_{PV}$), i.e. total consumption minus PV power produced, are rather stable per year (figure 4). Both show a seasonal pattern with higher values during winter. Seasonality is more pronounced for market demand as it is influenced by PV production. That is, the anyway lower demand during summer is even decreased by high PV output. Oppositely, demand and consumption are almost equal to each other in winter months when solar irradiation is weak. From the graph one gets the impression that the increased solar energy production (Q_{PV}) increases demand ($D-Q_{PV}$) volatility. But, it must be kept in mind that the seasonality occurs regularly and can be included in planning processes. Figures A.9 and A.10 (Appendix III) visualise the hourly consumption and market demand for the 16th of January 2016 and the 16th of July 2016. The dates are arbitrarily chosen but the effect stays the same for all winter and summer days respectively. One can see that on a winter day, the market demand follows almost the same pattern as total consumption major demand in peak hours. On summer days however, the demand does not exhibit its maximum at noon but around 18:30 when the sun starts to go down. Additionally, it is striking that the market demand curve is much flatter on the day in July than in January.



Source: SMARD, 2018

Figure 3: Installed PV capacity and PV power produced (2015-2018)

Prices seem to correlate positively with demand but are more volatile as they also depend on supply factors, such as input costs, availability of wind energy and costs of operation. For instance, one could look at the price spike in January 2017: During the last two weeks of the month wind power production has been far lower than expected so that the missing electricity had to be covered by other sources such as gas or hard coal plants producing at higher marginal cost (SMARD, 2018). On a daily basis, similar tendencies of price movements as for market demand cannot be observed (figure A.3). The daily price variability does not reveal a difference in strength between January and July. Instead, prices in January generally tend to be larger than those in July.



Source: SMARD, 2018

Figure 4: Monthly electricity consumption, market demand and price (2015-2018)

4 Results

The following sections present the results of the statistical analysis. The results of the cash flow analysis are illustrated. At the end, the effect of prosumption on large producers' revenue volatility is examined.

4.1 Results for risk of prosumer cash flows

Figure 5 displays the monthly average CF for the three scenarios. The baseline situation has the lowest variability, i.e. is almost constant, and yields the highest mean of the three scenarios with approximately 15 €/kWp and month. On average, saved electricity expenses contribute to approximately 58% of total cash inflows, earnings from feed in to 42% and saved costs from power outages to less than 0.1% applying the high price from Nooij et al. (2007).

In the prosumer liberalised (PL) situation, even the largest average CF in July (9 €/kWp and month) is just slightly higher than 60% of the average CF in the baseline while the fully liberalised (FL) scenario is characterised by similar CF per month as PL. Looking at figure A.4 explains higher CF for FL compared to PL in January, February, September, November and December: whilst retail prices for baseline and PL scenario are stable (28.72 €-cents/kWh), they fluctuate in FL. As the retail price is above average in January, February, September and November, prosumers are now able to exploit price differences (FL). A second effect coming into play in winter is the relation between production and consumption (figure A.1 in Appendix II). Output in January, November and December is less than 2.5% of annual output respectively and consumption slightly above average. That is, prosumers are able to realise high SCR in these months, which, combined with the price effect, lead to superior performance in FL compared to PL. However, during summer the picture changes as PV output is much larger than own electricity consumption so that earnings from feed-in play a dominant role regarding constitution of CF. Additionally, retail prices are below-average in that time resulting in lower CF, and thereby, inferior performance for FL compared to PL (figure A.4).

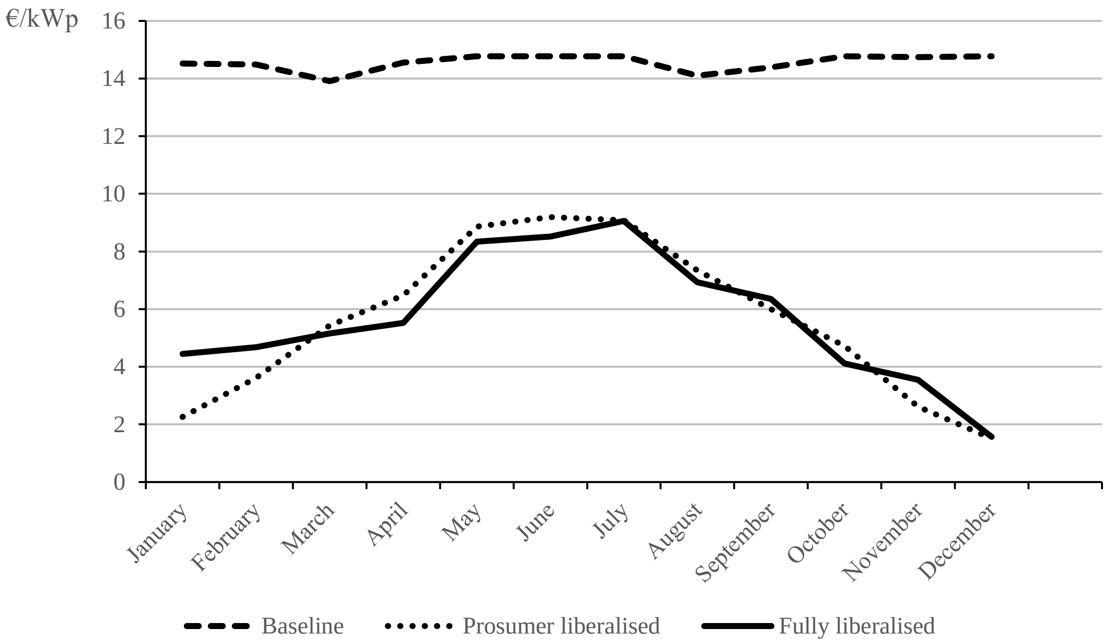


Figure 5: Average cash flows per month for all scenarios

Measures of volatility for prosumers within 2017 can be found in table 9. The average minimum cash flow per prosumer and month for the PL and FL scenario are negative meaning that the cash inflows are not able to cover the costs. The average range is the lowest for baseline (2.65 €/kWp) followed by FL (9.31 €/kWp) and PL (9.54 €/kWp). In the baseline situation, the deviation from completely constant cash flows stems from costs such as for replacement or maintenance not covered by insurances and maintenance contracts, or cleaning of the panels. By the introduction of wholesale prices and payments according to the load profile the average standard deviation increases from 0.77 €/kWp to 3.18 €/kWp. This combined with lower means results in a CV being on average 10 times higher than beforehand (baseline). For FL, the variability does also increase but not that strong (CV = 59.51%). Thus, even though FL implies an additional varying variable (retail price), CF volatility is lower than in PL. That is not only due to higher mean but also due to lower standard deviation.

The reason for larger means under FL conditions lies in the daily price cycle (figure A.3). In PL, retail prices are fixed while in FL, they follow the movements of wholesale prices which are stronger for winter days (figure A.3). Prosumers benefit from high retail prices during daytimes when PV panels produce power, hence leading to larger cash flows for FL. This effect only holds for months with comparatively low PV output. For the typical sunny months with high solar radiation (April until August), PL is characterised by larger CF. In that time, retail prices are below average even during peak hours (figure A.4). As the retail price is fixed at the mean of 28.72 €-cents/kWh (PL), PL's CF exceed FL's CF. However, the superiority of PL in summer is not to able to cause its overall mean to be larger than under FL.

Table 9: Averages of cash flow descriptive statistics for prosumers

	Baseline	PL	FL
Minimum [€/kWp]	12.12	-0.35	-0.25
Maximum [€/kWp]	14.77	9.19	9.06
Mean [€/(kWp*month)]	14.54	5.59	5.69
Total cash flow [€/(kWp*year)]	174.58	67.12	68.23
Standard deviation [€/kWp]	0.77	3.18	2.74
CV [%]	6.72	67.17	59.51

Remark: First, the minimum was calculated for each individual in the sample. Thereafter the average of all 71 minima has been computed. The same procedure is conducted for the other numbers.

A lower standard deviation for FL (2.74 €/kWp; 3.18 €/kWp for PL) also stems from interseasonal price movements. While the high winter retail prices induce a large gap between CF of FL and PL in winter (figure 5), prices being slightly below average in summer lead to lower CF for FL in summer (figure 5). Thus, the average FL standard deviation is smaller than under PL conditions and, combined with a larger mean, could be considered as less risky based on CV.

4.2 Influence of prosumers on large producers' revenue volatility

The average daily CV of revenues for large producers are reported in table 10. The maximum value is 108.39 in November 2016 while the lowest value is 24.21 in July 2018. In winter, variability is typically higher than during summer. The fact that months in spring obtain quite different CV over the years can be explained by unreliability of weather conditions. A spring with quickly changing weather leads to fluctuating demand and different availability of wind and solar power, thereby causing revenues of big market players to vary.

Figure 6 shows daily CV of large producers' revenues plotted against daily PV output. The majority of CV lie between 0.2 and 0.6 while some values appear to be extremely large and some slightly lower. Note that the maximum of the ordinate is set equal to two to allow a proper visual inspection of the data (see Appendix III for all values). A clear relationship between CV and PV output is not visible in the graph. Instead, comparing the occurrence of values larger than 0.6 it seems that with increasing PV output the amount of these values decreases. Spearman's rank correlation coefficient is -0.2566 and significant ($p<0.01$). That is, for days with comparatively large solar power production the variability of large producers' revenues is comparatively low.

Table 10: Average daily CV of revenues of large producers [%]

	2015	2016	2017	2018
January	53.33	41.05	37.46	51.74
February	36.17	42.95	38.25	32.06
March	43.60	51.63	34.16	60.04
April	61.62	29.77	52.12	39.86
May	44.06	63.24	34.60	80.32
June	32.62	30.21	33.81	28.17
July	34.35	28.87	34.42	24.21
August	32.88	32.65	34.24	
September	51.36	34.73	33.72	
October	35.94	30.71	52.06	
November	44.41	108.39	41.55	
December	48.90	92.82	70.83	

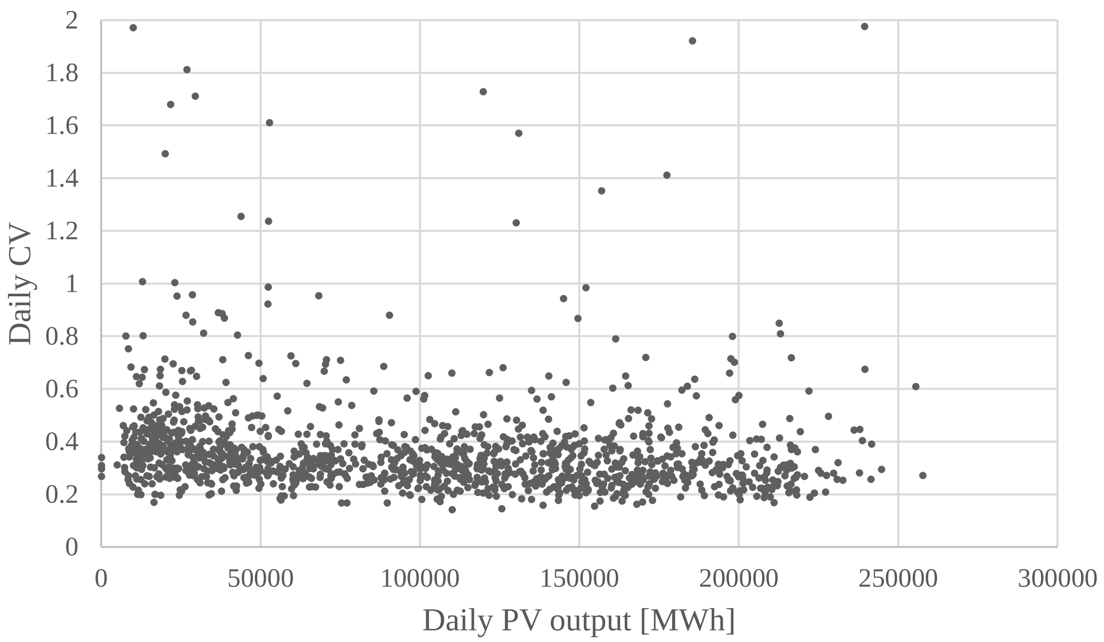


Figure 6: Daily CV of large producers' revenues dependent on daily PV output

5 Discussion, conclusion and future research

The chapter discusses and concludes the results of this research which are contrasted with the literature. This includes a reflection on choice of method and data for the analysis. The conclusion follows and lastly potential future research is pointed out.

5.1 Discussion

The scenario analysis showed that most important producer risk coming into play for prosumers in Germany is policy risk which was also stressed in studies on PV operation (e.g. Arnold & Yildiz, 2015; Gatzert & Vogl, 2016; Ioannou et al., 2017). As already indicated in chapter 2, this political uncertainty affects other risk factors such that a change in law and regulation results in substantial increases in cash flow volatility by inducing price and production risk. Price (e.g. Muñoz et al., 2009; Bhattacharya & Kojima, 2012; Biondi & Moretto, 2015) and production risk (e.g. Gross et al., 2013; Hirth, 2013; Zeng et al., 2015) are the other two major producer risks based on the mentions in literature. Hence, the results are in line with the identified risks by other authors. Concerning consumer risks, decreasing financial consumer risk is one of the two major motivators to become a prosumer (e.g. Schleicher-Tappeser, 2012; Kästel & Gilroy-Scott, 2015; Biggar & Reeves, 2016). As saved electricity expenses contribute to approximately 50% of the prosumer cash flow, it confirms previous publications. Secondly, reducing performance risk was identified to be important to consumers for engaging in prosumption (e.g. Juelsgaard et al., 2014; Kästel & Gilroy-Scott, 2015; Liebrati & Giorgio, 2018). Contrary, avoided costs of power outages only contribute to a mere fraction of prosumer cash flow in the presented analysis. The contradiction might be caused by an underestimation of the power outage costs per minute. The values from Nooij et al. (2007), Carlsson & Martinsson (2008) and Reichl et al. (2017) are averages across the population. However, it might be that especially those consumers who start producing their own electricity value guaranteed access to power much higher than the average. This would hence explain why mitigated performance risk is important to prosumers but could not be confirmed due to the utilisation of the power outage costs per minute from the three publications.

The advantage of the descriptive methodology chosen is that risks and their quantitative impact on prosumer cash flows delivered an objective risk measure. Compared to other methods such as stochastic modelling, using real data does not impose restrictive assumptions on variable distributions, and hence does not hide information partly. On the other hand, the results of the risk analysis of prosumers are only valid for 2017. In case variables such as solar irradiation, wholesale and retail prices are different in other years, the outcomes of the real-data based approach used here are likely to change. Hence, new data generation would be necessary to make risk statements for other years. A stochastic simulation approach would then be advantageous as key parameters in the probability distributions can be adjusted easily.

Besides, the sample for the prosumer risk analysis is not representative for the population as mainly plants have been included being larger than 30 kWp though the vast majority is smaller than or equal to 10 kWp. Smaller plants might be slightly less affected by policy changes as they usually entail larger self-consumption of approximately 50 percent of the total PV output compared to about 25-30 percent for plants >30 kWp. That is, they do not suffer as much from the price drop for power fed into the public grid (from 12.74 €-cents/kWh in FIT scheme to 3.72 €-cents/kWh (WP)) because they do not feed in as much as larger plants. Hence, mean cash flows and CV of smaller installations might change slightly less under different policies than the average plant in the given sample. Nevertheless, the overall consequences under market liberalisation would stay the same for smaller plants as well.

Earlier analyses found a negative correlation between residential PV production and electricity prices (e.g. Paraschiv et al., 2014; Rintamäki et al., 2017) which is one of the most important risk factors for large electricity producers (e.g. Park et al., 2011; Thakur & Chakraborty, 2016; Werner & Scholtens, 2017). Another risk factor is the volatility of demand that large producers face (Daskalakis & Markellos, 2009; Thakur & Chakraborty, 2016). In this study, the correlation between volatility of the product of both elements (price and demand), i.e. the revenues of large producers, and PV output is analysed which is also negative as for PV production and electricity price. The correlation is rather small (-0.2566) and the visual inspection of the CV plotted against PV production suggests that on days with larger solar power production the number of very large CV of revenues tend to decrease. However, this correlation does not imply causality. The large CV mostly occur in winter when indeed output from PV plants is low. At the same time wind power generation is large so that there will probably be a positive correlation between production quantities of wind mills and CV of revenues of large producers. Whether wind energy increases the volatility of revenues of large producers or PV production decreases it cannot be answered with the chosen method which is a drawback of the simple correlation analysis.

5.2 Conclusion

- The risk profile of German electricity prosumers comprises mainly policy risk from the producer side and financial consumer and performance risk from the consumer side.

Large producers are mostly concerned with input and output price volatility as well as financial risk. Prosumers can form organisations which take influence on policy makers to avoid changes in the support scheme and expand their power production capacities to decrease financial consumer and performance risk. Large producers have other possibilities due to their scale such as diversification, markets for financial derivatives or installing more flexible plants.

- Currently, the only fluctuations in monthly CF (CV = 6.72%) for a prosumer are caused by cost fluctuations. Based on the fact that saved electricity expenses account on average for 50% of the cash flow, financial consumer risk is first important risk factor for prosumers. Accounting for policy risk indicates that a market liberalisation would imply substantial growth in cash flow variability under in two different policy scenarios (CV = 67.17% and 59.51% respectively).
- Lastly, prosumer activity correlates negatively with the daily volatility of revenues of large scale producers by influencing residual demand and electricity prices. On days with large solar power output the number of very large CV of revenues of large producers is smaller in the observation period.

5.2 Future research

The strong differences in cash flow variability between baseline and the other policy scenarios for the prosumer risk analysis show that risk is a very relevant topic for prosumers. As literature on prosumer risks and their impact on other market actors' risks is very limited, further research is needed. It is also important to examine how prosumers can manage the risks they face to facilitate their financial planning and keep their operations profitable. For instance, other studies may conduct an analysis of PV prosumer cash flows with the same scenarios as presented and estimate the effect of adopting risk management measures such as storage devices on the volatility of returns.

Based on the finding that a market liberalisation would lead to a significant increase of cash flow volatility, additional investigation is necessary to analyse the effects of the risk increase on prosumer activities in Germany by incorporating models of decision-making under risk. Other investment opportunities for consumers should then be taken into account such as capital markets, real estate or precious metals. The comparison of the investment alternatives with prosumption under market liberalisation will allow to make predictions of future prosumer development which contributes to the goals of the German government in the energy transition.

Future analyses regarding the influence of prosumers on large producers' volatility of returns might build a model to capture costs of power production at each point in time. This could be implemented to find out the effect on profit fluctuations which is usually a more important target measure compared to revenues.

A decreasing impact of prosumers on profit volatility for large producers might open possibilities for collaboration between them. For instance, large producers could help consumers who are interested in installing a PV system, i.e. becoming a prosumer with planning of the plant tailored to the prosumer's needs. Prosumers could in turn provide real time data on their PV output and electricity consumption to large producers to facilitate their shot-term production planning. These possibilities should then also be explored.

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Appendix I: Transcript of prosumer interview

In the following, the interview with the prosumer couple Mrs and Mr Mohr resident in Düren (wife (W), husband (H) and interviewer (I)) is given. The interview has been taken place on the 16th of June 2018 from 16:00 until 16:37.

[phasing in]

I: Is it okay for your that I record the conversation?

W: Of course, no problem. As long as it will not be played in public [laughter].

I: Okay, thank you! Generally, why did you install the solar panels on your rooftop?

H: The primary reason was to invest capital and receive a return. That was the primary reason. The secondary reason was to do something for the environment. That was simply the combination. Why did it take so long? I thought a long time about whether such an installation on the rooftop looks nicely or if we impair the look of the house with it. Yes… and that was a topic we thought about for many years.

W: Yes, some years.

H: And last year, the municipal utility organised an event and said, "Come over, we will present you something."

I: Ah, okay.

H: Yeah, and that was the moment when the topic evolved.

I: Okay. Would you say now that the look of the house got worse by the panels?

W: No!

H: No!

W: If we knew that it would look like that, we would have done it way earlier – especially since we used the maximum area on the rooftop that we can use… these almost 10 kWp that you can put on the rooftop at one time. And by dedicating half of this to the front side and the other half to the back side, it is not even that noticeable so that it looks much better than we imagined.

H: One has to explain why almost 10 kWp.

W: Maybe he [the interviewer] does not want to know that.

I: [laughter] No, please go on.

H: Umm, there is a category in size as a power producer when you have to pay the EEG apportionment. And when you stay below the 10 kWp, you are producing primarily for your own household and the apportionment is omitted. And that is simply an additional interesting fact that has to be considered as producing power for selling is not worthwhile to think about due to the low prices at the moment paid for electricity plus the EEG apportionment. The only advantage that the laws has kept open or provides is that after one year you can increase the size of your installation by 9.9 kWp.

I: So every year, you can increase the size of the installation by 9.9 kWp?

W: Every year, yes.

H: Yes, every year. You can continue installing until you do not have any space left on the rooftop. And that is also interesting while planning the installation that we – we still have free space – can add the same area to the existing one.

I: Okay. And how is the exchange with the utility grid contractually arranged?

W: Well, as soon as the installation starts producing power, the electricity is used within the house. And if then more power is produced by the rooftop than we can use, the surplus will be delivered to the grid. That was the arrangement until March. In March, we added the 9.9 kWp and bought a storage device. Now, the electricity that is produced will be used inside the house and when the consumption is insufficient, but still produce, the storage is filled. And only after the battery being fully charged, we start feeding into the grid. Through that, it becomes clear that the primary goal is to use the produced power ourselves. And we decided to buy the storage later on as we are the typical household where no power is consumed during the day. That is, as soon as we started producing power, we purely fed it into the grid except the few electricity using devices that we have such as fridges and stand-by devices. But that is actually nothing. And then, by the battery which is fully charged in the evening in case of normal weather, we are able to cover the consumption from the moment of coming home in the evening until the late morning of the next day. And, there is a software which enables us to scan 24 hours, 7 days a week and throughout the whole year the produced power, the power fed into the grid and the power taken up by the battery. However, to be able to do that, your installation has to be registered at the Bundesnetzagentur

[Federal grid agency] so that the provider of the storage has access to your data. Thus, we can see how much we sell and how much we buy – it happens from time to time that we have buy electricity.

H: When you have a bad Sunday, the battery maybe is discharged already at 3 in the night and we have to buy.

W: But we are really put into the position that we are self-sufficient up to 93-94% since we can measure it, i.e. since we have the storage. Beforehand, I did not have the possibility to monitor.

H: The storage, of course, is flexible in size. You can choose a larger size but that is not good for the storage because it would not be fully discharged. Best for these batteries is to discharge them down to 10% or even further and then being fully charged again. This leads to a longer lifetime. And the installations are too expensive to buy a larger battery which has a shorter lifetime. But, you can extend that. As already mentioned, one can enlarge the installation size to the backside so that you can store the power, and taking into account the possibility of driving an electric car, the power consumption increases by far leading to adopting a larger storage device being reasonable. As the electric cars are consuming much more electricity than we could produce at the moment, it would be interesting to store the power from a larger installation in the larger storage to avoid the costs for the electricity used by the car.

I: Then, the storage will probably be empty in the morning when the car is fully charged?

W: [laughter] Yes pretty fast.

H: These are just thoughts. Be found that to be an interesting issue for the future.

W: On the other hand, the storage cannot handle it to be discharged ad hoc, i.e. too fast. Therefore, you can also program that the power is not taken out of the battery in certain situations, e.g. when we turn on our sauna.

I: How was it before the storage was bought? Did the utility measure what has been demanded and what has been produced?

H: No, that has been done automatically by the meter. Like right now, when a certain amount of power is produced which is too much to put into the storage, the battery is only charged with two thirds of the power and the other third is fed into the grid and sold. As soon as the battery is fully charged and no consumption takes place, everything is fed into the grid.

W: Until the battery has been introduced, we only had one possibility to monitor how much electricity is produced. We had to look at the meter and compare it to the previous month or to ask the utility company.

H: Well, you have to try to adapt the own consumption a bit. For instance, we did not start the dish washer in the evening after dinner but programmed it so that it started the next late morning.

W: Yes, you rethink your behaviour regarding the power consumption. When you know that the sun is shining and we are producing electricity, we start the washing machine, tumble dryer and dish washer. The awareness of the own patterns changes and you adapt the behaviour. And, we are quite glad with it. We will turn into those organic people [laughter].

H: No, not really. You always must ask yourself what you save and what you do not save. You get a feeling what a Kilowatt actually is. Sitting in the garden and turning on the garden illumination for an hour or two, it costs you maybe 30 cents. I have them [laughter]. Therefore I do not sit here in the dark. On the other hand, when you have such an installation and washing machine consumes three or four kW per hour, it is reasonable to run it during the daytime instead of during the night, And these are the things that you have to be aware with regards to financial issues before we say that we are getting crazy by saving.

I: Of course, the relations have to be appropriate. What is fed back into the grid right now is reimbursed at the feed-in rate, right? Is it fixed or does it fluctuate?

W: Correct, it is fixed.

I: Also during the next 20 years?

H: Yes, as long as the policy makers do not change it, it will stay fixed. The FIT is less than the half of our electricity price for consumption.

W: Yes it decreased a lot. It has been much higher but has been reduced more and more.

H: Yes we waited quite long but has been the right investment at the right point of time. The question was to put the money on a savings book or fixed deposit account where you have to pay to put your money soon. You pay interest that you leave your money there. These are things that are absolutely idiotic. So I consider such investments as better and more efficient.

W: Yes, the return on investment from the saved electricity expenses is definitely higher than what you would get by investing the money elsewhere.

I: Okay. What does such an installation cause in terms of running costs?

H: None.

I: Repair? Nothing?

H: Well, one tried to offer us a maintenance contract but at the same time told us behind closed door that it is stupid. When an installation suffers from a short because a marten bites through the cable, somebody has to come and check it. Whether you need a maintenance contract for that, I doubt.

W: Thus, we do not have these costs.

H: The only thing is that one must talk to one's own household insurance company regarding damage caused by hail or something similar like lightnings.

W: So the solar panels are included into the building insurance. So things like hailstones in size of tennis balls or a marten on the rooftop would have to be considered but not in our case.

I: You mentioned earlier that the FIT is fixed as long as the policy makers do not change it. Could it be the case that the FIT changes through a legislative change?

H: To be honest, I do not know. But to come back to running costs, there are some companies that sell cleaning contracts for the panels together with the installation which is also not necessary. Only if you have a flat roof, it might be useful to clean them after two or three years. These are costs that might occur.

I: Are there any technical problems so far?

H: So far, we did not have any technical problems. Of course, it could be that there happens something but as far as we know these installations are not prone to technical failures.

I: And would you say that you are less affected by power outages since you have the installation?

H: We would not be affected at all now. However, during the 13 years that we live in this house, there was only one power outage. Hence, this cannot really be regarded as a motivation to invest in solar panel installations.

I: Okay! Thank you very much four your time and the valuable information!

Appendix II: Data and additional graphs for prosumer risk analysis

Table A.1: Data collected with telephone survey of 71 prosumers

Plant number	FIQ [kWh]	FIT rate [€/kWh]	SC [kWh]	RP [€/kWh]	S [kWp]
1	475.50	0.13	9,034.50	0.29	10.00
2	20,198.40	0.12	6,732.80	0.31	26.30
3	562.80	0.18	10,693.20	0.30	12.00
4	23,718.40	0.16	5,929.60	0.30	34.00
5	38,675.70	0.11	4,297.30	0.30	49.00
6	482.50	0.12	9,167.50	0.29	10.00
7	6,725.76	0.12	2,241.92	0.29	9.92
8	478.00	0.12	9,082.00	0.29	10.00
9	1,619.49	0.13	6,477.95	0.26	8.84
10	65,471.00	0.11	28,059.00	0.29	99.50
11	5,765.76	0.12	2,471.04	0.29	9.36
12	26,447.95	0.12	3,268.85	0.30	30.00
13	478.00	0.12	9,082.00	0.29	10.00
14	4,856.22	0.13	4,856.22	0.29	9.18
15	485.00	0.12	9,215.00	0.29	10.00
16	25,704.00	0.12	17,136.00	0.31	42.00
17	37,083.20	0.13	15,892.80	0.29	56.00

18	941.00	0.12	8,469.00	0.29	10.00
19	130,182.25	0.11	130,182.25	0.30	275.00
20	1,997.24	0.18	7,988.96	0.31	9.80
21	7,192.80	0.13	1,798.20	0.29	9.00
22	2,104.96	0.13	2,104.96	0.29	4.16
23	18,417.00	0.13	7,893.00	0.30	30.00
24	1,434.00	0.12	8,126.00	0.29	10.00
25	7,300.80	0.13	4,867.20	0.30	12.00
26	5,394.01	0.13	3,596.00	0.31	9.89
27	1,434.00	0.13	8,126.00	0.29	10.00
28	24,654.08	0.13	6,163.52	0.29	29.92
29	14,060.00	0.12	21,090.00	0.29	38.00
30	3,540.06	0.13	1,517.17	0.23	5.83
31	4,871.17	0.13	2,509.39	0.28	7.65
32	136,563.78	0.11	21,313.42	0.25	162.76
33	10,560.00	0.13	7,040.00	0.29	20.00
34	5,997.60	0.13	2,570.40	0.30	8.40
35	4,236.43	0.12	8,961.17	0.27	14.04
36	8,560.72	0.13	18,275.39	0.29	30.68
37	79,783.28	0.11	88,891.73	0.30	195.00
38	15,569.28	0.12	11,460.72	0.28	30.00

39	1,509.17	0.12	7,420.84	0.29	9.10
40	96,306.59	0.11	17,396.59	0.28	132.60
41	7,744.50	0.12	25,912.62	0.29	35.28
42	22,272.00	0.13	5,568.00	0.30	30.00
43	1,611.04	0.12	8,272.62	0.29	9.97
44	491.12	0.13	6,524.88	0.30	8.00
45	38,325.83	0.11	12,639.37	0.21	51.48
46	123,214.69	0.11	37,221.11	0.30	163.71
47	3,687.25	0.12	4,887.75	0.29	8.75
48	6,525.00	0.13	2,175.00	0.28	10.00
49	45,459.37	0.11	9,844.00	0.29	59.53
50	37,104.42	0.12	18,192.78	0.29	60.90
51	36,564.13	0.12	1,875.87	0.29	40.00
52	6,936.76	0.13	1,018.24	0.21	8.60
53	11,368.00	0.17	2,842.00	0.29	14.00
54	27,720.00	0.11	9,240.00	0.28	42.00
55	75,701.97	0.11	7,213.66	0.29	85.54
56	3,412.69	0.12	3,682.30	0.29	7.65
67	55,689.56	0.13	18,563.19	0.29	85.25
68	234,831.84	0.16	10,808.16	0.29	276.00
69	4,492.57	0.13	2,143.43	0.29	7.00

60	26,668.80	0.15	2,963.20	0.30	32.00
61	13,275.00	0.14	119,475.00	0.29	150.00
62	38,603.25	0.16	2,031.75	0.29	43.00
63	125.44	0.13	5,328.56	0.24	6.00
64	82,470.96	0.11	10,193.04	0.29	108.00
65	5,666.18	0.12	1,789.32	0.28	8.06
66	21,392.50	0.15	21,392.50	0.29	43.00
67	412,277.04	0.16	48,882.96	0.29	540.00
68	10,151.90	0.12	2,981.22	0.27	14.56
69	491.04	0.12	5,646.96	0.30	6.60
70	60,040.00	0.11	15,010.00	0.29	79.00
71	478.00	0.12	9,082.00	0.29	10.00

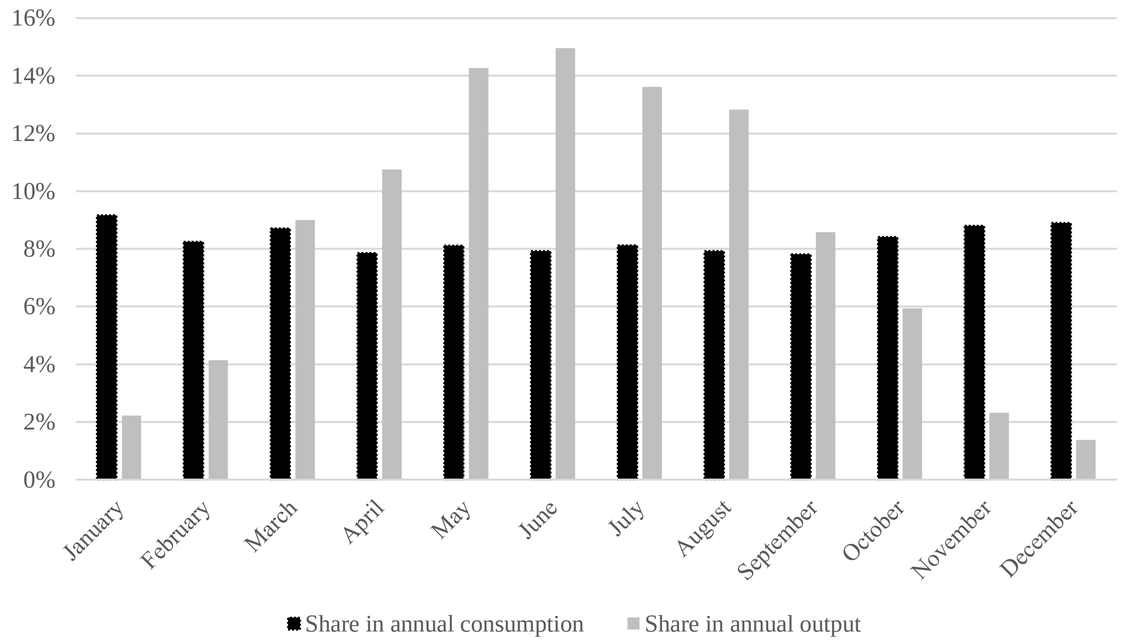
Table A.2: Cost data for plants of survey respondents

Plant number	January	February	March	April	May	June	July	August	September	October	November	December
1	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
2	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
3	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
4	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00
5	190.00	14.00	14.00	500.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
6	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
7	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42
8	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
9	10.33	10.33	10.33	10.33	10.33	10.33	10.33	10.33	10.33	10.33	10.33	10.33
10	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67
11	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	98.33	8.33	8.33	8.33
12	10.08	10.08	10.08	10.08	10.08	10.08	10.08	10.08	10.08	10.08	10.08	10.08
13	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
14	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
15	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
16	7.50	7.50	7.50	7.50	7.50	7.50	7.50	117.50	7.50	7.50	7.50	7.50
17	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00	52.00
18	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
19	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25

20	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
21	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67	8.67
22	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42	10.42
23	6.67	6.67	127.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67
24	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
25	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	231.00	21.00	21.00	21.00
26	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08
27	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
28	39.00	39.00	39.00	39.00	39.00	39.00	39.00	39.00	39.00	39.00	39.00	39.00
29	20.00	248.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
30	54.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75
32	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
33	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
34	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
35	18.58	18.58	18.58	18.58	18.58	18.58	18.58	18.58	18.58	18.58	18.58	18.58
36	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92
37	13.33	13.33	13.33	13.33	13.33	13.33	13.33	13.33	13.33	13.33	354.33	13.33
38	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
39	16.75	16.75	16.75	16.75	16.75	16.75	16.75	16.75	16.75	16.75	16.75	16.75
40	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08

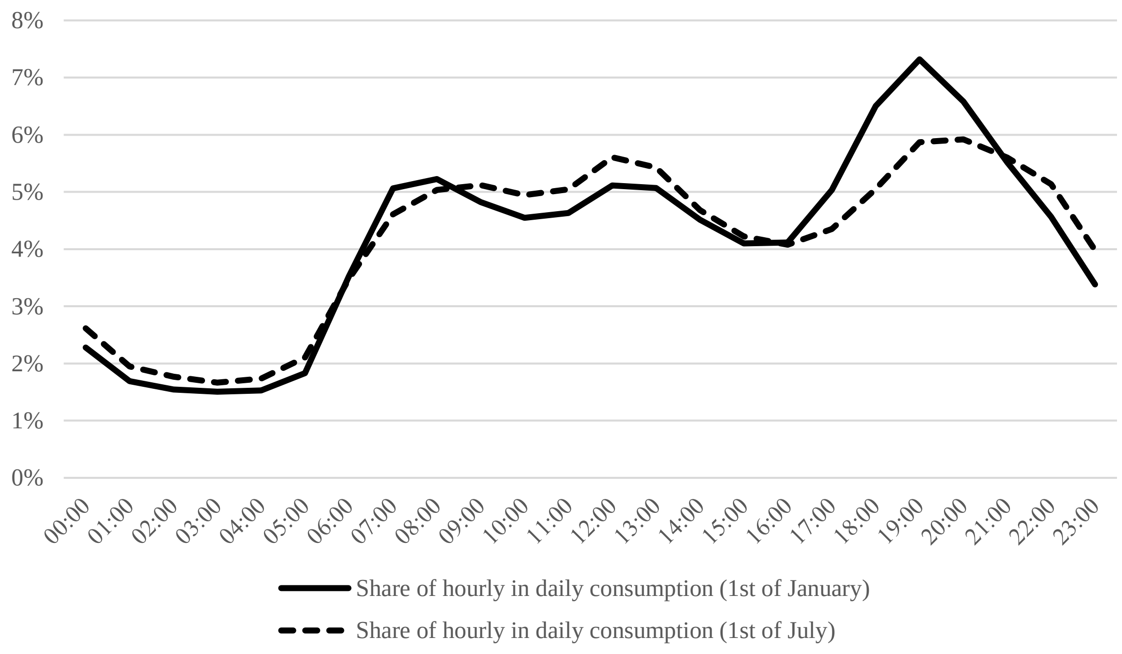
41	15.17	15.17	15.17	15.17	15.17	15.17	15.17	15.17	15.17	15.17	15.17	15.17
42	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
43	12.00	12.00	264.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
44	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
45	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50
46	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58
47	16.58	16.58	16.58	16.58	16.58	16.58	16.58	16.58	16.58	16.58	16.58	16.58
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	19.25	19.25	19.25	19.25	19.25	19.25	19.25	19.25	19.25	19.25	19.25	19.25
50	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
51	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
52	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
53	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
54	8.17	8.17	8.17	8.17	8.17	8.17	8.17	8.17	8.17	8.17	8.17	8.17
55	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75
56	10.00	10.00	10.00	10.00	10.00	10.00	10.00	321.00	10.00	10.00	10.00	10.00
57	12.00	12.00	12.00	232.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58
59	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00
60	29.00	478.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00
61	25.00	25.00	25.00	425.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00

62	49.00	49.00	49.00	49.00	49.00	49.00	49.00	49.00	49.00	49.00	49.00	49.00
63	10.17	10.17	10.17	10.17	10.17	10.17	10.17	10.17	10.17	10.17	10.17	10.17
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	43.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	11.00	11.00	11.00	11.00	11.00	11.00	11.00	221.00	11.00	11.00	11.00	11.00
67	26.67	26.67	26.67	26.67	26.67	26.67	26.67	26.67	26.67	26.67	26.67	26.67
68	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75
69	74.00	74.00	285.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00
70	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58
71	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00



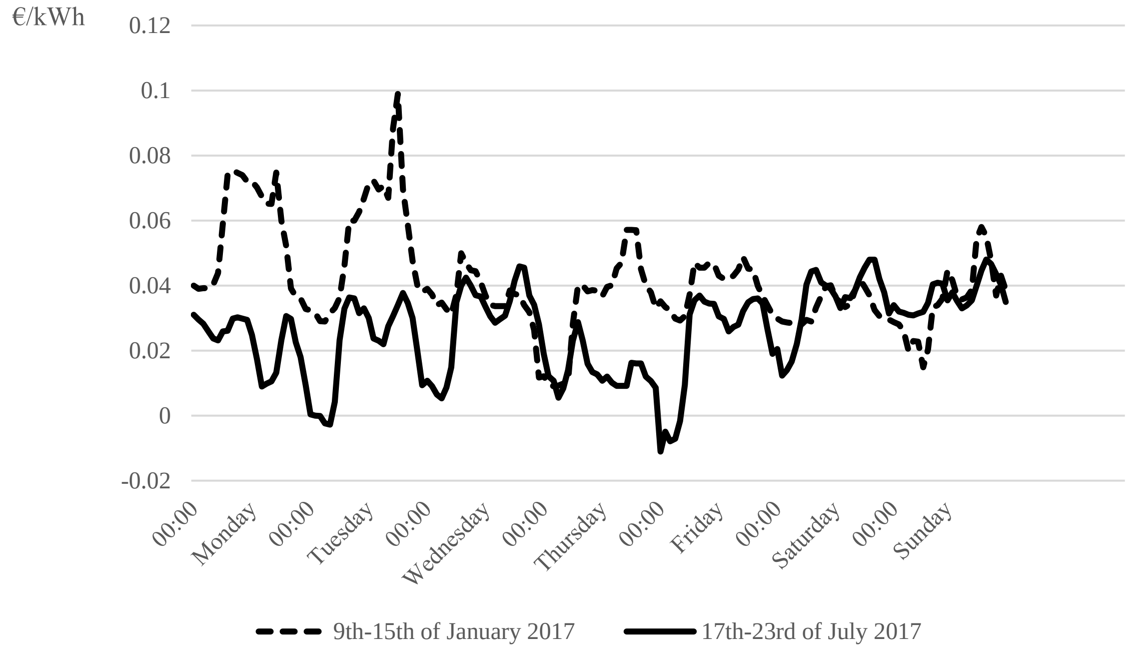
Source: BDEW, 2018; SMARD, 2018

Figure A.1: Shares of monthly in annual quantity of consumption and PV output (2017)



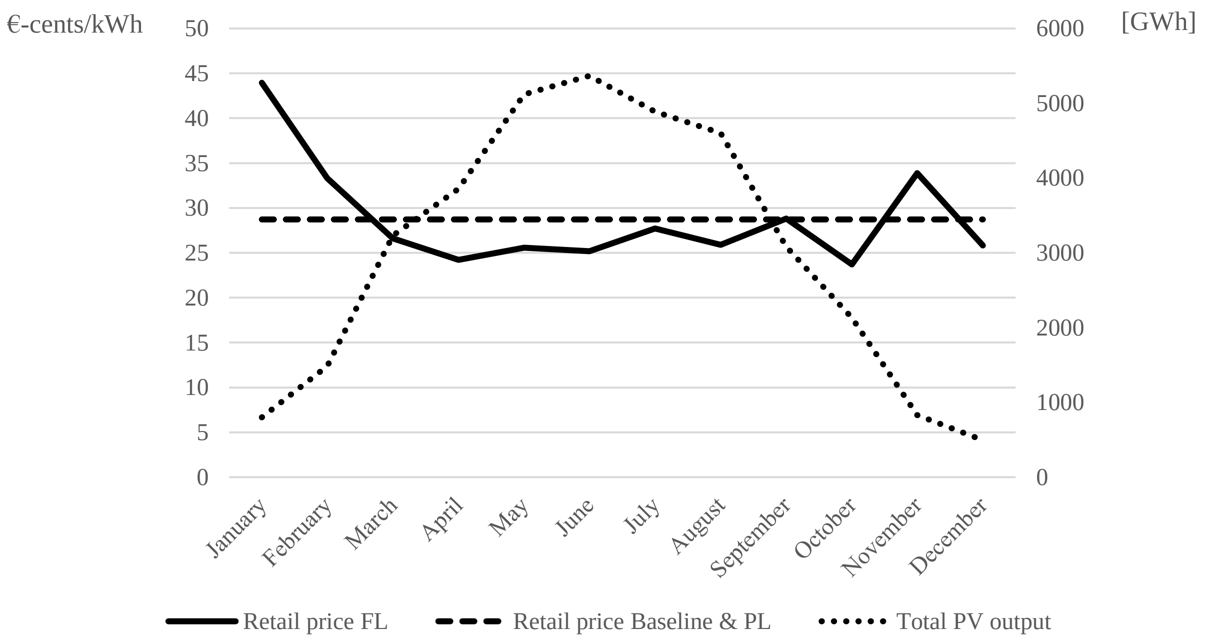
Source: BDEW, 2018

Figure A.2: Standard household load profiles as hourly share in daily consumption



Source: SMARD, 2018

Figure A.3: Hourly wholesale prices



Source: SMARD, 2018

Figure A.4: Monthly retail prices and PV production (2017)

Appendix III: Data for the influence of prosumers on large producers

Table A.3: Descriptive statistics of hourly power consumption, PV output, market demand and electricity price

Variable	Minimum	Maximum	Mean	Standard deviation
Wholesale price [€/MWh]	-130.09	163.52	32.24	14.73
Power consumption [MWh]	19,821.00	79,062.50	55,710.25	10,088.44
PV power production [MWh]	0.00	28,665.00	4,123.67	6,290.00
Market demand [MWh]	19,574.50	79,062.50	51,586.58	9,931.68

Source: SMARD, 2018

Table A.4: PV development in Germany (2015-2018)

	Newly installed PV capacity[a] [MWp]	Total PV capacity[a] [GWp]	PV power produced[b] [GWh]
2015			
Jan	122.68	38.13	481.09
Feb	98.98	38.35	1288.41
Mar	97.18	38.45	2858.58
Apr	79.50	38.53	4435.39
May	65.27	38.59	4411.59
Jun	64.83	38.66	4552.82
Jul	75.19	38.73	4917.50

Aug	66.70	38.80	4612.57
Sep	73.62	38.87	3226.21
Oct	77.65	38.95	1946.35
Nov	60.88	39.01	1136.48
Dec	117.21	39.12	850.93
2016			
Jan	65.29	39.19	654.33
Feb	50.49	39.24	1249.17
Mar	71.14	39.32	2370.12
Apr	63.05	39.38	3708.58
May	87.90	39.47	4716.77
Jun	90.48	39.56	4574.82
Jul	74.30	39.63	4835.77
Aug	81.77	39.71	4622.52
Sep	96.65	39.81	3793.81
Oct	102.88	39.91	1612.96
Nov	121.80	40.03	1004.23
Dec	376.45	40.41	771.33
2017			
Jan	113.83	40.52	798.42
Feb	73.59	40.60	1484.97

Mar	102.33	40.70	3230.60
Apr	118.13	40.82	3856.85
May	136.06	40.95	5120.31
Jun	118.11	41.07	5366.86
Jul	139.31	41.21	4886.34
Aug	113.84	41.33	4602.79
Sep	105.80	41.43	3079.29
Oct	109.46	41.54	2130.32
Nov	87.32	41.63	831.02
Dec	81.95	41.71	494.44
2018			
Jan	186.54	41.89	729.77
Feb	107.50	42.00	1830.49
Mar	120.60	42.12	2703.50
Apr	198.73	42.32	4836.12
May	156.87	42.48	5931.82
Jun	183.66	42.66	5336.90
Jul			6167.37

Sources: a = Bundesnetzagentur 2018a; b = SMARD, 2018

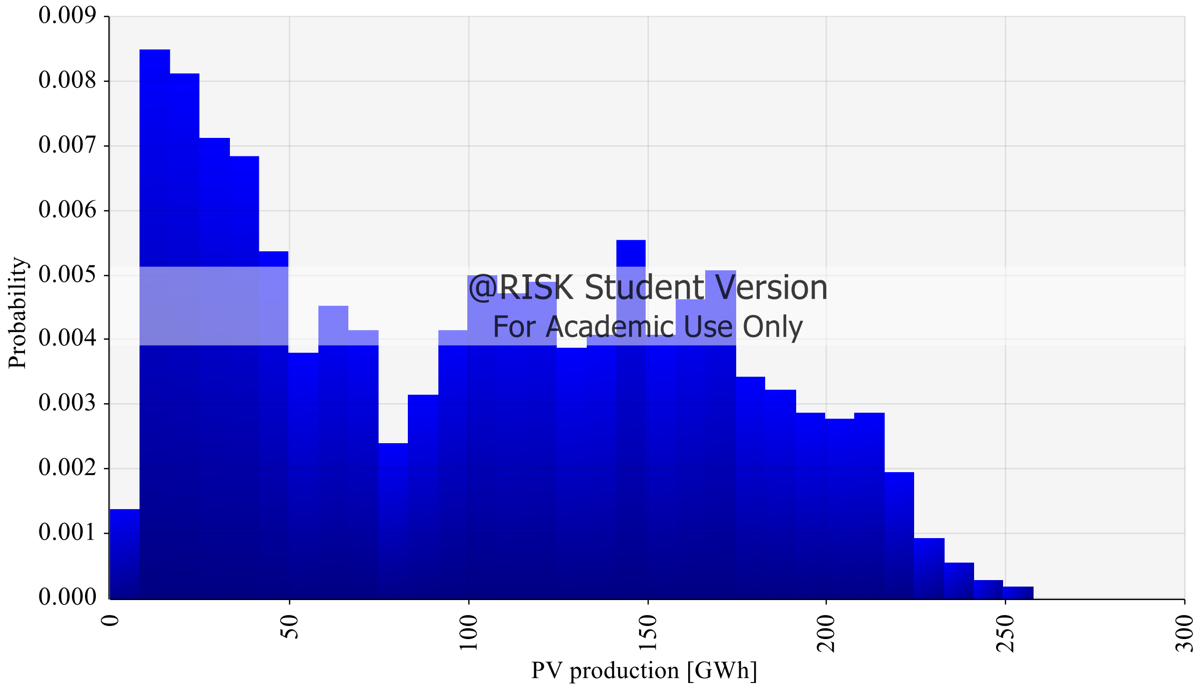


Figure A.5: Probability density function of daily PV production (2015-2018)

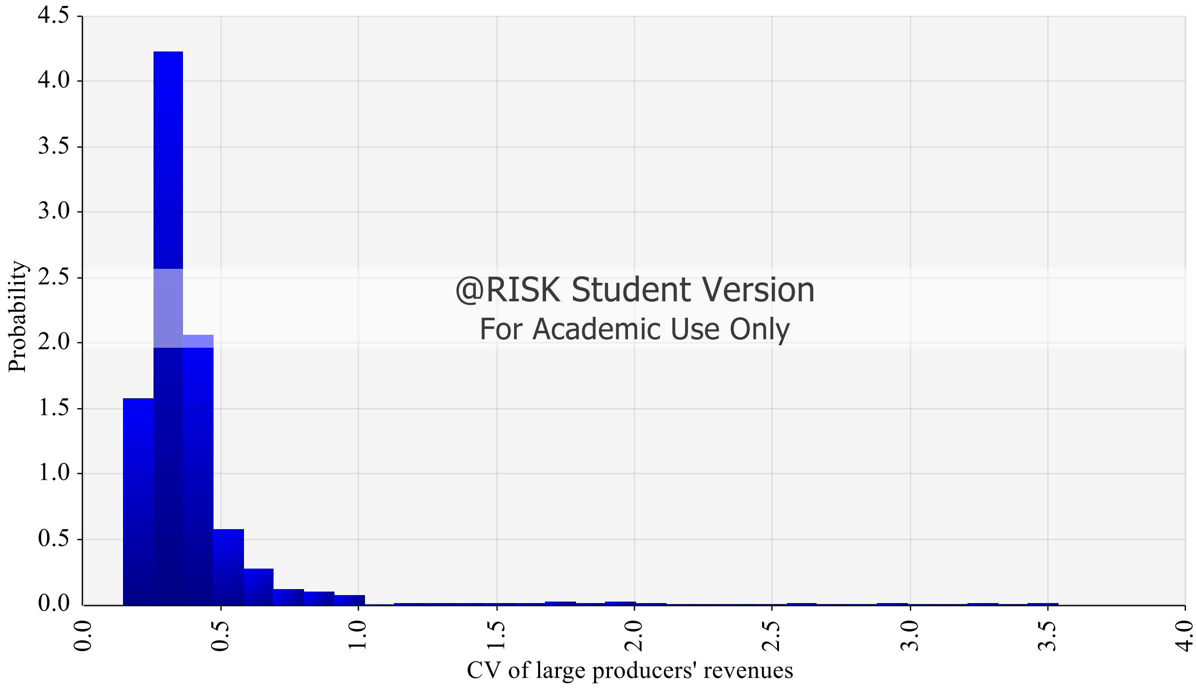
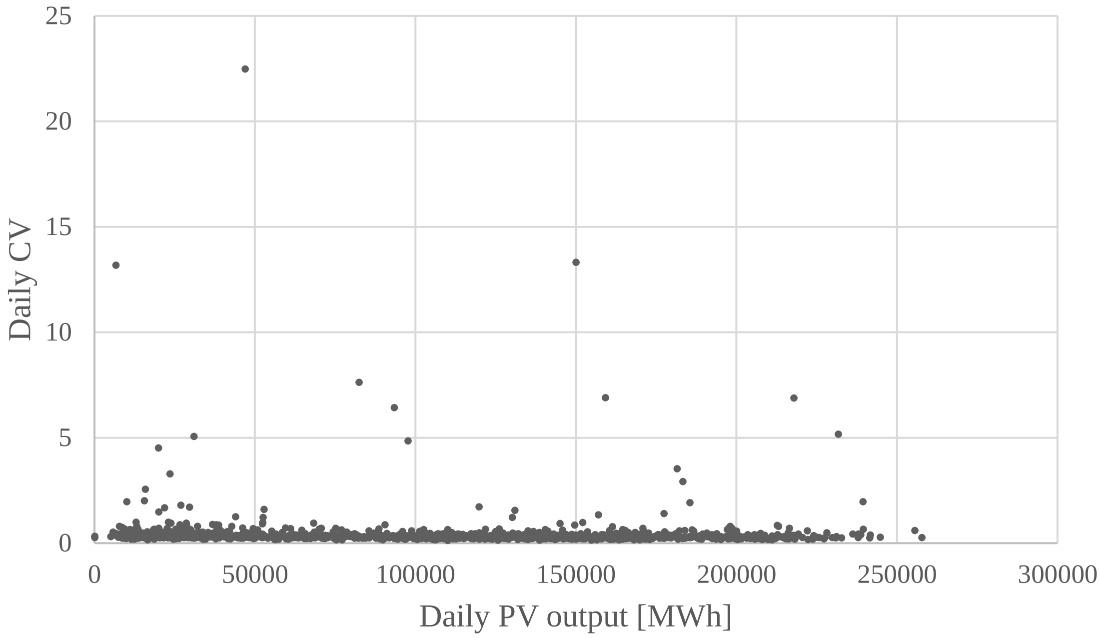
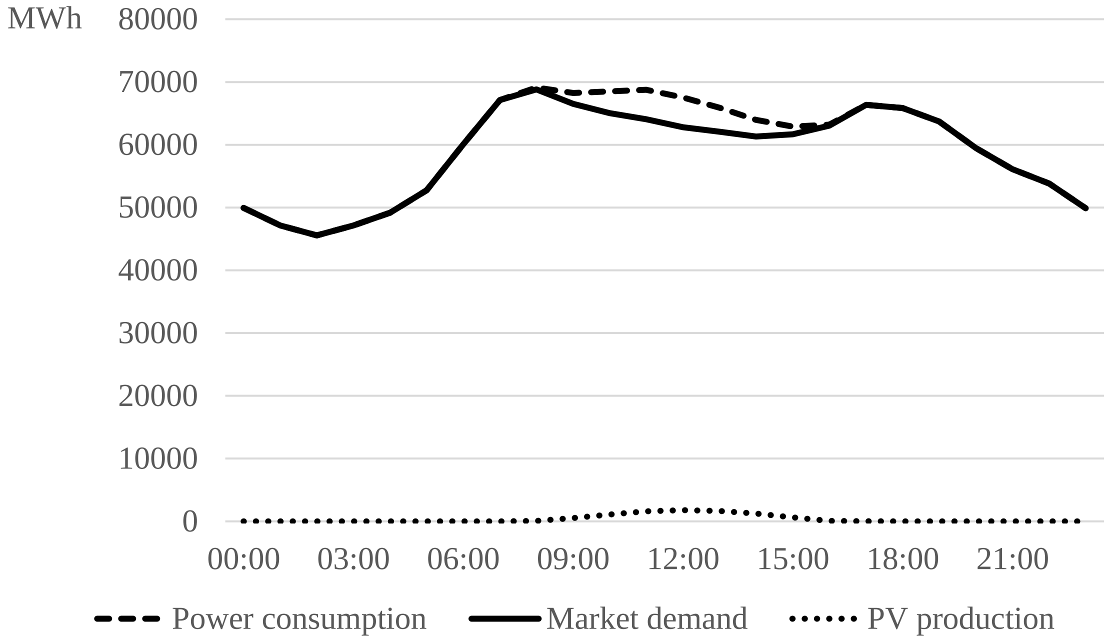


Figure A.6: Probability density function of CV of large producers' revenues



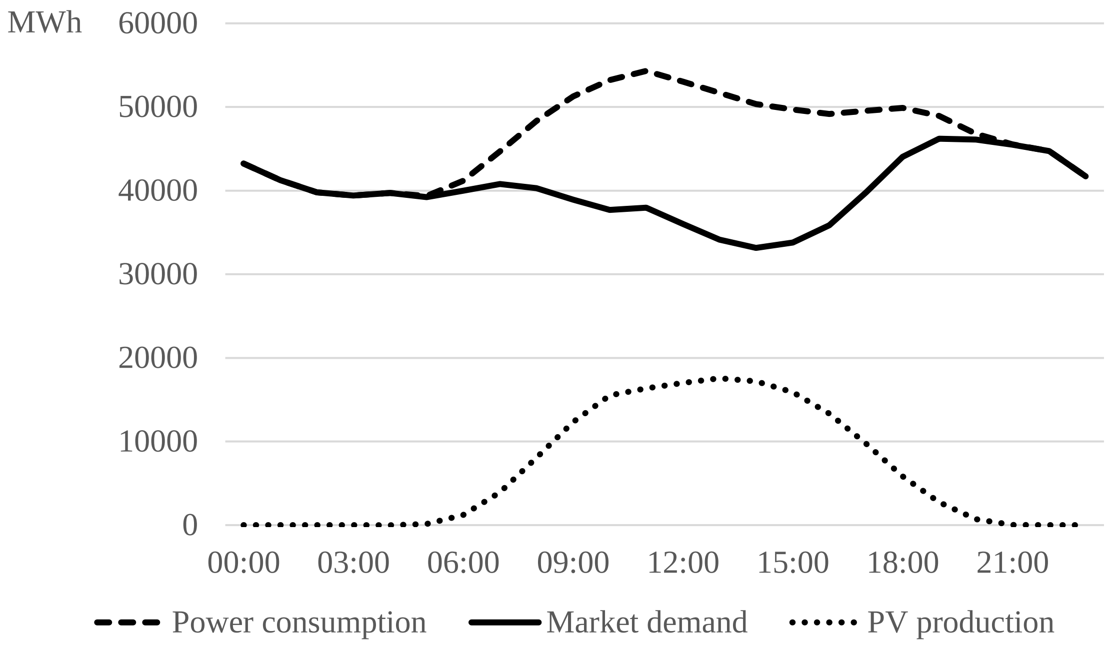
Source: SMARD, 2018

Figure A.7: Daily CV of large producers' revenues dependent on daily PV output including all observations



Source: SMARD, 2018

Figure A.8: Hourly power consumption, market demand and PV output (16th of January 2016)



Source: SMARD, 2018

Figure A.9: Hourly power consumption, market demand and PV output (16th of July 2016)