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The German Case of Clean Energy Transition: How Grid Customers Perceive Regulatory Requirements, esp. Photovoltaic 'Obligation to Install'

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Abstract: Whilst Germany's transition towards renewable energy sources is gaining momentum, such as, new photovoltaic installations numbers have multiplied over past three years, new policies' implementation is yet to be fully rolled out to all grid customer segments. First, this paper systematically lays out current developments in the areas of decentral renewable energies generation, electrification of heating & mobility, and supply grid operators. We carefully reflect on the institutional factors driving and shaping current developments. Second, the study focusses on grid customers' perception of new legislation that imposes the installation of photovoltaic systems onto roofs. We find that despite a majority supports the 'obligation to install', other pull factors may still be more important in shaping the decision-making process towards purchasing a photovoltaic system.

Keywords: distribution system operator; DSO; electricity grid; energy transition; photovoltaic obligation; renewables

1 INTRODUCTION - GERMANY'S CLEAN ENERGY TRANSITION IS GAINING MOMENTUM

Clean energy transition ranks on top of European Union's political agenda. Energy is a centrepiece of the EU Green Deal, which wants to reach carbon neutrality by year 2050. The policy sets ambitious goals for the pathway toward climate neutrality, and notably, the energy sector to date accounts for three quarters of the European greenhouse gas emissions [1, 2]. The sector is key to carbon neutrality, as it for instance provides the foundation for decarbonisation of mobility and heating.

The Renewable Energy Directive (revised 2023) defines targets on renewable energy sources usage, that is, to reach a minimum share of 42.5% of EU's gross final consumption of energy by 2030. EU member countries commit to contribute as specified in separate, national climate action plans. [3]
In the case of Germany, the action plan is embodied in a bundle of both federal and state-level legislations. The transformation of Germany's energy system toward clean energy started last decades but will be pushed further in the years to come: Renewable energies are required to cover 80% of year 2030 electricity demand, with full decarbonisation to be achieved by 2045. [4]

Tab. 1 depicts installed electricity generation capacity of renewables by end 2020, Germany. Renewables contributed already 45% to total German electric power generation for the year 2020. Which highlights how ambitious the German targets are, if benchmarked with EU targets.

Table 1 Installed capacity of renewable energy, 2020, Germany [5] (Tab. 19, p. 58, translated)

Technology	Installed generation capacity in GW at 31st Dec 2020
Onshore wind	54.4
Offshore wind	7.8
Photovoltaic	53.7
Biomass	8.8
Run-of-river	3.9
Other	0.6

Long-term forecasts of electric power generation for Germany can be found in the 'Grid Development Plan'. By 2045, the share of renewable energies shall rise to more than 91%, all scenarios. Note that this goes along with significantly risen gross electricity consumption – 953.5 or 1128.2 TWh respectively are forecasted scenarios for year 2045 [5].

The German Renewable Energies Act spells out incentives for the adoption of renewable energies, as well as it establishes a framework for customers' remuneration. The expansion of electricity grids is a government key priority and hence facilitated by this legislation [4].

The act does recognise the important role of distribution system operators. Namely, they integrate decentralized, renewable energy sources and batteries into the grid; they also make the grid absorb new sources of electricity demand, e.g., from electric vehicles. The distribution grid then is where 'smartness' will come in: Particularly, enabling flexibilisation of consumption respectively demand via smart meters and adjustable/ adaptable electr(on)ic appliances [6-9]. This paper is dedicated to analyse the transition from a distribution system operator' perspective.

2 ELECTRICITY DISTRIBUTION SYSTEM OPERATORS ARE FOCAL TO ENERGY TRANSITION

The German electricity grid consists of transmission and distribution grids.

Transmission grids carry large amounts of electric power over longer distance, for instance, from offshore and onshore wind turbines to the industrial centres in southern Germany. Such grids operate on extremely high voltage level. The latter, distribution grids run mostly on low or mid voltage. They distribute electricity to households and to industry. Distribution grids must cope with raising electricity demand triggered by electric vehicles or heat pumps, as well as integrating decentralised energy generation, e.g. from photovoltaic systems.

Distribution and transmission grids are operated by separate legal entities in Germany: If an energy company counts more than 100k customers, electricity suppliers and distribution system operators must become legally unbundled entities from each other and act as separate, for customers distinguishable companies [10]. Distribution system operators maintain, operate, and extend the electricity grid. They have an obligation to purchase and to remunerate for decentralised generation of electricity, e.g. from private households operating photovoltaic (PV) systems or from wind park operators. Remuneration is calculated by statutory feed-in tariffs, which are set at a level to promote renewables [4]. Distribution system operators consequently are a key contact for grid customers, electricians and planning companies because distribution system operators manage the grid connection process and keep records of the capacity of the local grids.

The electricity distribution system operators' perspective is exemplified by the company Netze BW GmbH. Alongside with TransnetBW GmbH for transmission grids, it is a legally unbundled subsidiary company of integrated energy supplier EnBW AG. Netze BW GmbH is the largest electricity distribution grid operator in the German state of Baden-Württemberg.

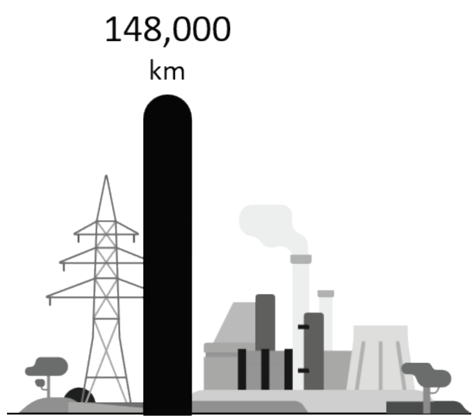

Figure 1 Transmission & distribution grid length of TransnetBW GmbH and Netze BW GmbH, dated 2023 [11] (adapted)

The German clean energy transition impacts distribution grids. The so-called "Network development plan 2037/2045" sets out some scenarios and development paths, projected for until year 2037 respectively climate neutrality reached year 2045. Key points are [5]:

- Compared with year 2020, renewable energies' share approximately to double – potentially up to 91% in the year 2045;
- Energy generation to decentralize and therefore will become more complex to manage for grid operators; and
- Clean energy transition to experience a major rebuild of distribution grids capacity ('once in a generation task').

For the state of Baden-Württemberg, PV systems' expansion matters most of all in lieu of fast increasing clean energy generation. This is due to favourable solar radiation in the southern as opposed to northern German states and, limited potential of wind turbine energy [13].

For an overview of the increase of German PV energy generation and different scenarios see Tab. 2.

Table 2 Overview of KPIs: Germany's forecasted electric power generation & consumption until year 2045 [5], (Tab. 1, p. 24, adapted, translated)

Scenario and year	Base at 31st Dec 2020	A	B	C	A	B/C
		y. 2037			y. 2045	
Electric power generation (installed capacity in GW)						
Photovoltaic	53.7	260	280	320	325	395
Renewable electric power generation	131.4	411.9	450.4	506.4	521.4	623.9
Electric power generation. Total	215.7	463.2	501.3	557.3	568.4	670.4
Electricity consumption(in TWh)						
Net electricity consumption (est.)	478.0	725.6	793.1	872.9	890.4	1064.5
Gross electricity consumption (est.)	532.8	778.7	846.4	926.4	953.5	1128.2
Share of renewables on gross electricity consumption (est.)	45%	>86%	>87%	>88%	>91%	>91%

Tab. 2 illustrates photovoltaics' role for renewable-based electric power supply across Germany: long term or until 2045, photovoltaics will by far become the most important renewable electric power source if accounted by installed capacity. Note that about half of the installed PV capacity stems from installations mounted on roofs, the other half from larger scale ground-mounted installations.

3 PHOTOVOLTAIC 'OBLIGATION TO INSTALL' IN SEVERAL GERMAN STATES

To accelerate the uptake of renewable energies from roof-mounted PV systems, a number of German states legislated obligations for property owners to install PV systems. Such 'Obligation to Install' applies to a) new built houses, b) when roofs are renovated, or c) where new parking lots are built. Aim is to unlock potential suitable surface areas for photovoltaics.

Our study focusses on above 'Obligation to Install' and for the state of Baden-Württemberg. The obligation has been applicable to different segments since different dates:

- since 1st January 2022 for non-residential builts and parking lots with more than 35 lots;
- since 1st May 2022 for residential, new buildings; and
- since 1st January 2023 for roof replacement/full roof refurbishment of existing buildings.

At least 60% of suitable roof surface shall be used for PV installation [13, 14].

In order to increase panel size of the study, we identified similar 'Obligations to Install' in other German states. Similarity assumed if obligation shows same timeline characteristics or scope. E.g., date of introduction, or scope residential vs. non-residential. Tab. 3 provides an overview of similar PV obligations across the German federal states.

It shall be noted that the sample is representative for the key decision-making criteria and property ownership status of participants albeit it is not fully representative for German population. We e.g. excluded states that introduced a PV

'Obligation to Install' for only public buildings. For private residential buildings, the obligation affects many grid customers, so that this focus of our study is most relevant.

Table 3 Overview of similar German PV obligations incl. closing dates

Scope	Non-residential, new buildings	Residential, new buildings	Roof replace-ment/full refurbishment	Parking lots	
Baden-Württemberg	YES 01.01.2022	YES 01.05.2022	YES 01.01.2023	YES 01.01.2022	[13, 14]
Berlin	YES 01.01.2023	YES 01.01.2023	YES 01.01.2023	NO	[15]
Hamburg	YES 01.01.2023	YES 01.01.2023	YES 01.01.2024	YES 01.01.2024	[16, 17]
Rhineland-Palatinate	YES 01.01.2023	NO	NO	YES 01.01.2023	[18]

Distribution system operators are the main point in policies' implementation. As far as distribution system operators are concerned, grid customers' attitudes and public perception de facto shapes policy communication. It determines what guidance and support becomes accessible to customers. And a good communication of distribution system operators could simplify grid connection processes as well as prevent additional respective follow-up inquiries by grid customers and by electricians.

4 REPRESENTATIVE SURVEY OF GRID CUSTOMERS: FACTORS IMPACTING UPON ATTITUDES AND PURCHASE DECISIONS FOR PHOTOVOLTAIC SYSTEMS

The survey was motivated by the industry's need to better understand the range of attitudes and motives of grid customers installing PV systems. This became a strategic need to respond to the state of Baden-Württemberg's new regulatory requirement of 'Obligation to Install' photovoltaics: Does the public perceive the obligation stipulated by the new regulatory requirements as positive, and fair?

Recent literature has showcased the relevance of fairness and justice to successfully establish and scale up new energy policies in modern societies [19, 20, 21]. More research is needed into the particulars for specific energies and countries. Our study makes a focussed contribution to that debate.

We wished to gain insight how relevant this obligation is to the decision-making process of grid customers. We argue that electricity distribution system operators need to know which factors have which impact on decisions to install PV systems, as well as the timings and reasons in the process. Findings can be used to design better approaches of informing grid customers and to address the demand of connecting PV systems to distribution grids.

4.1 Methodology and Sample

To document the state of knowledge and attitudes of the public in regard to upcoming or existing photovoltaic obligations, we selected German federal states that are similar and including Baden-Württemberg. Similar in terms of what regulatory requirements were to be implemented and when (as discussed in the previous section). The practical use of the data is to inform grid customers on their new PV 'Obligation to Install' more effectively.

Method of data collection was a large, representative set of short online interviews (approx. 10 minutes), conducted January 2023. The data was collected and compiled by the market research institute mindline energy GmbH.

The sampling targeted participants 18 years and older, from the states of Baden-Württemberg, Berlin, Hamburg, and Rhineland-Palatinate. The selection was then further narrowed down by these criteria:

- Survey participant is decision maker for energy supplier of their household, and
- Survey participant owns a residential or non-residential building, or s/he does plan to build one, and s/he
  - a) already owns a photovoltaic system or,
  - b) plans to install such within the next 12 months or,
  - c) is not currently mind-settled against new installations.

Sample size total n = 501, which consists of n = 200 owners of photovoltaic systems, n = 189 planning an installation within the next 12 months, and n = 112 non-rejecters. The sample is composed representative of gender.

We did not include straight opponents of the installation of Photovoltaic (PV) Systems into the panel, because we expected only minor insights from this group on how to improve communication to the public, respectively to grid customers.

4.2 Results: Majority Supports PV 'Obligation to Install' – Focus on Positive Perception and Fairness

The main reasons in favour of installing PV systems were safe energy supply, lower electricity costs, and environmental motivations. 'Obligation to Install' appears to be of secondary importance for acquiring a PV system.

Fig. 2 provides an overview of reasons for installing a PV system.

We also asked whether respondents are aware of PV obligations because the new regulatory requirements have only been implemented recently in Germany. However, most of the respondents were already familiar with implied obligations. Note that owners of non-residential buildings, for whom PV 'Obligation to Install' has already taken effect months earlier, do show a significantly higher level of awareness. Berlin, in general, records a higher level of awareness in our data set. Fig. 3 shows the results.

Information sources for respondents who stated being aware of the PV obligations are: press/ media (73%), internet incl. forums (41%), respondents' commissioned electricians (11%), as well as distribution system operators (9%). Meaning that both, electricians and distribution system operators are only involved to low extent into the information perceived by customers.

We further quizzed respondents about how they assess their level of information in PV obligations. 4 out of 10 feel that their information level is very good (14%) or good (24%). 38% at least state they're informed. 19% of the respondents perceive being badly informed or 4% not informed at all, respectively.

The level of information can be considered of particular importance when it comes to the perception of the PV obligations. It shapes the attitude of respondents. See Fig. 4 for details.

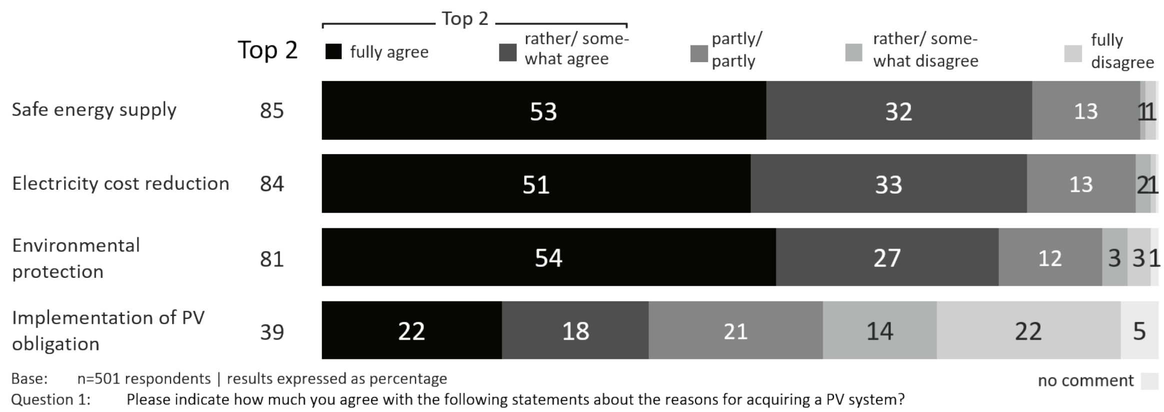

Figure 2 Reasons in favour of purchasing a PV system

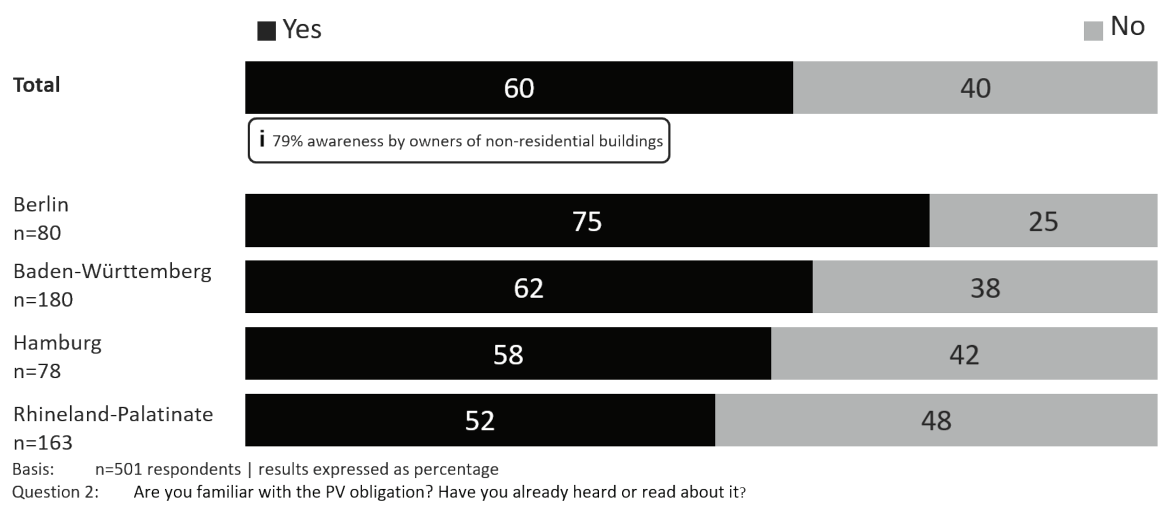

Figure 3 Awareness of PV 'Obligation to Install'

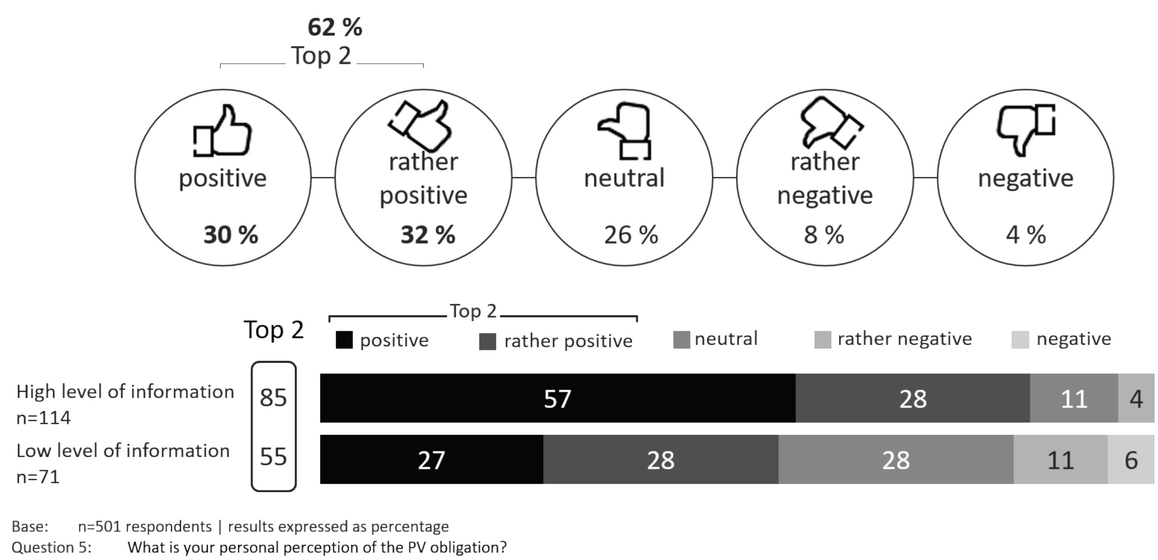

Figure 4 Individual perception of PV 'Obligation to Install'

Overall, we find a clearly positive perception of the 'Obligation to Install'. In addition, the more respondents are informed about it, the more positive appears to be their perception.

Besides individual perception, we asked the panel about fairness of the 'Obligation to Install'. This is a crucial point to any law makers: Legislation should be perceived as fair, for it to become widely accepted across society. Where an obligation is perceived as unfair, it may yield valuable lessons to be learned for future making of legislations.

54% of the respondents perceive PV obligations as fair – only 20% as unfair (26% do not know/ did not respond). This is again a clear majority in favour of the PV obligations. Fig. 5 sums up respondents' reasoning of perceived fairness vs. unfairness:

Figure 5 Top three reasons of perceived fairness vs. unfairness of PV obligations

An 'Obligation to Install' is perceived as fair, in principle. The survey participants particularly considered environmental protection and energy efficiency. Respondents who perceive it as unfair are mainly concerned about additional financial burden. In this context, also rejection of coercion itself is an issue of grid customers.

4.3 Discussion of Findings

Our study yields rich insight into the purchase decision of PV systems, and in consumers' context.

Key points are safe energy supply, energy costs, and environmental protection. Implementation of the newly introduced PV obligation as such is rather of secondary motivation. It shall be noted for context that during the data collection period of this study, energy prices went high and secure energy supply got challenged in the wake Ukraine war. However, we observe a strong support of the general public in favour of the PV obligation across selected German states. Concerns on the other side are dominated by fear of additional financial burden.

Data is from selected German states having introduced similar PV obligations. While environmental protection and secure supply priorities & objectives may be generalisable to other countries pushing clean energy transition, energy prices may differ. Therefore, results have to be read with a pitch of salt. Some are context specific for Germany, some may apply internationally. It was not the purpose of this paper to develop general theory. The sample composition implies some constraints: we do not have insight into a control group of customers rejecting PV systems at all, as such opposing customers were taken for not being interested to participate in interviews inquiring the new PV regulatory requirements.

5 CONCLUSIONS

Clean energy transition is clearly gaining momentum not just in policy making but also regarding its implementation. We observe ambitious plans and targets of decarbonisation of electricity generation both, on European and national levels. Our analysis did stress the importance of distribution grids if for the share of renewable energy sources to increase.

Especially, distribution systems operators are focal actors to manifold stakeholders: They manage the grid connection of decentralised electric power generation and, are key contact to grid customers and commissioned electricians. This fact highlights how the 'Obligation to Install' in selected German states serves as a device unlocking scaling-up the potential of PV systems and fostering renewable energy sources' share upon total electricity consumption.

We argue that it is crucial for legislative action to be widely accepted by the public, if to be effective long-term. For the PV 'Obligation to Install', we spot evidence of wider new policy acceptance: The higher the individual information level about the obligation is, the more positive its perception. Focussed, relevant information seems crucial for wider acceptance of policies enforcing PV obligations. However, in the individual perception of, and purchase decision for photovoltaic systems, some other motives seem to overshade the policy: Especially, cost savings for electricity, and safe supply. In addition, environmental protection is stated as motivation. The energy cost savings are a market-based mechanism incentivising installation of PV systems. Nevertheless, we want to shed light on the perception of 'fairness'. For policy makers it should much more guide the design of legislation in future. Since additional costs for installation of a photovoltaic system are the most prominent root cause of perceived unfairness, the costs should be addressed in their structure and allocation. This aligns with prior studies finding that installation costs are an important factor [22] respectively which highlight effectiveness of incentives in the promotion of (residential) PV systems (i.e. direct subsidies, tax deductions, feed-in tariffs) [23, 24, 25]. One could therefore establish smarter public grant schemes for property owners, to reduce perceived unfairness.

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