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The Role of Photovoltaics in Energy Transition – Assessing the Prospects for a Regime Shift

In Austria, photovoltaics makes up only a small percentage of total power generation. Nevertheless, expectations of experts are rather bright that this technology has significant growth potential and will thus be contributing to a transition of the Austrian energy system.

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Abstract
Photovoltaics is still a niche technology, accounting for a low proportion of electricity generation. Combining an analysis of strengths, weaknesses, opportunities and threats (SWOT) with the analytic hierarchy process, we discuss the prospects and challenges relating to photovoltaics in Austria, when attempting to move from a niche level to a regime level change in energy transition. In carrying out this hybrid method, a set of pre-defined SWOT factors were judged by experts by means of pairwise comparisons. As results reveal, strengths and opportunities outweigh weaknesses and threats. According to the experts, financial and technological considerations dominate over environmental and social issues. Hence, characteristics such as rapid reduction in module costs, technological progress and low economies of scale imply that significant promise may be assigned to photovoltaics in terms of its expected contribution to the transformation of our energy system.

Keywords
analytic hierarchy process, decentralized energy generation, energy transition, photovoltaics

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There is a broad consensus that a transition from fossil fuel based energy systems towards renewable energy is necessary in order to mitigate climate change. A possible pathway for such an energy transition lies in an intensified usage of photovoltaic (PV) energy. In recent years, the amount of energy generated by PV technology has increased rapidly in several countries. As the costs associated with photovoltaics continue to fall, its potential for further expansion continues to rise.

The multi-level perspective (MLP) of socio-technical systems (Geels 2002) provides a good starting point for gaining a more comprehensive understanding of the role of photovoltaics in energy transition. Within the MLP framework, the technological transition of the energy system, and the potential for PV technology, can be explained by using a hierarchy of structuring processes which operate at three different levels (Geels 2005): *niche* (micro), *regime* (meso), *landscape* (macro).

In transition literature, the niche level plays a central role in the emergence of novel technologies (Kemp et al. 1998). New energy practices and (technological) innovations, such as photovoltaics, emerge in protected spaces or market niches, then evolve over time, and – where sufficiently successful – start to compete with the dominant energy regime (Geels and Schot 2007, Raven 2007). In Austria, which is the focus of this study, PV technology can still be seen as a niche technology since at present approximately only one percent of electricity generated in Austria (626 gigawatts per hour) originates from PV plants.[1] The growth potential is clearly visible, though: as of the end of 2013, the installed PV capacity in Austria toted up to 626 megawatts$_{peak}$, a plus of over 263 megawatts$_{peak}$ (42 percent) compared to 2012 (Biermayr et al. 2014). At niche level, specific activities can influence the transition pathway of photovoltaics. Such activities comprise, for instance, suitable actor networks, which then support PV transition by gen- >

1 Figures according to a press release of the *Climate and Energy Fund* of the Austrian government: *www.klimafonds.gv.at/presse/presseinformationen/2013/bilanz-photovoltaik-jahr-2013*.

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erating common expectations, visions and learning processes on a number of different dimensions (Schot and Geels 2008).

The regime, the core element of the MLP framework, represents a highly interrelated and stable structure at the mesolevel. The current fossil fuel based energy regime is characterized by market structures, regulations, norms, user practices and policies (Markard and Truffer 2008). In Austria, an example for such regulations and policies in the field of photovoltaics are subsidies via above-market feed-in tariffs. These subsidies, which aim to promote solar power, are generally guaranteed for 13 years. However, the amount of available subsidies has always been capped, and recent policies seem to be directed towards slowly fading out such tariffs. More precisely: the dominant regime also incorporates the "selection environment" (i. e., the socio-technical environment created by actors, institutions and regulations) of PV technology in the energy transition.

The macrolevel is formed by external factors (e. g., climate change). They influence the development of the whole energy system but also constrain the regime members.

Embedded in this hierarchical structure of levels, PV transition is explained via the interaction of developments on the niche level competing with structures on the regime level. In Austria, the transition pathway to an increased usage of photovoltaics is mainly based on rather small and decentralized structures. Due to the relative scarcity of open areas for the construction of large-scale PV plants, in practice there has been a clear preference for widely dispersed roof-attached or building-integrated solutions.

The main objective of this paper is to identify and assess the prospects and challenges faced by PV technology in attempting to compete with the prevailing dominant energy regime in Austria. Above all, we have to determine and analyze the most important circumstances and conditions that might foster PV technology and contribute to a change at the regime level, that is, the relevant regulations, norms, user practices, policies, etc. To this end, we carried out an analysis of strengths, weaknesses, opportunities and threats (SWOT) and combined it with an analytic hierarchy process (AHP). In the context of the AHP, we evaluated and quantified the relative importance of the various SWOT factors. The evaluation and quantification of the respective factors is based on a dataset of expert opinions. Such an integrated SWOT-AHP approach has not yet been applied in the context of energy transitions, and provides us with a systematic assessment of how domain-specific experts evaluate the role of photovoltaics in energy transition in Austria.

Defining and Analyzing the Set of Relevant Factors

As mentioned above, we based our study on a standard SWOT analysis. Such an analysis pinpoints the relevant strengths and weaknesses, which are associated with a product or technology, and highlights any related opportunities and threats (Kotler et al. 2010). However, a fundamental drawback of the SWOT approach is that it merely represents a qualitative analysis and thus cannot be used to assess quantitatively the impact of each individual factor. To overcome the problem we applied the AHP method developed by Saaty (1980, 1999), which involves pairwise comparison and then weighting of the SWOT factors in terms of a specific hierarchy of priorities. For this purpose, we conducted a questionnaire among experts. All respondents have had considerable experience dealing with projects concerned with PV adoption. They were asked to judge the relative importance of the SWOT factors identified as significant.

Hence, the combined SWOT-AHP approach, first introduced by Kurttila et al. (2000), aims at increasing the effectiveness of a primary SWOT analysis as a decision making tool by making comparison of alternatives more commensurable. The approach has been applied successfully in systematic analyses in a number of different domains, for example, in the telecommunication sector (Mehmood et al. 2014), tourism (Kajanusa et al. 2004) or in agriculture (Shrestha et al. 2004). To the best of our knowledge, this is the first application of a SWOT-AHP analysis in evaluating the potential of PV technology in energy transitions. Typically, SWOT analysis is used as a structured planning method to define the internal strengths and weaknesses as well as external opportunities and threats of a company or product in order to achieve a certain objective within the organization. In our case, the SWOT approach is used to evaluate a technology and thus to assess the internal and external factors associated with photovoltaics.

In order to apply the SWOT-AHP method, we implemented a two-stage study design. Based on both a review of the relevant literature as well as on findings of previous studies on the attitudes towards photovoltaics (Brudermann et al. 2013, Reinsberger and Posch 2014) we first identified the most important factors for each SWOT category, selecting for methodical reasons three key factors in each group for further analysis. Since the selection of SWOT factors can never be entirely objective, we validated factor choice by including an open-format question for each SWOT section in the questionnaire, asking experts whether they would consider any other factors than the ones we had chosen as being more important.

Second, for pairwise comparison and weighting of the SWOT factors, we carried out a survey of expert opinion during a transdisciplinary workshop entitled *Transition to Smart Living Environments*. The workshop provided a platform for experts to discuss and work on transition processes in four different areas: building, transport, production and energy. The energy module included the topic of transformation of our current energy system through the usage of photovoltaics. A mixed group of 36 experts (academics, practitioners) took part in the workshop. The group of practitioners comprised regional policy makers, PV plant operators and planning experts, representatives from national interest groups and energy consultants, as well as energy providers. The questionnaire was distributed to all 36 workshop participants and returned by 21, yielding a response rate of 58 percent. Such an approach is always subject to limitations and potential bias. However, by taking this into account we managed to end up with a well-bal-

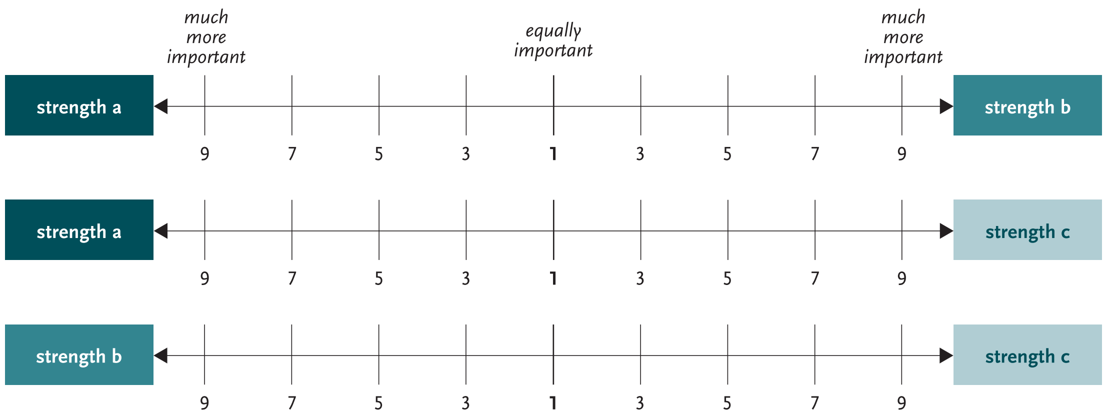

FIGURE 1: Sample for the pairwise comparison of factors in the group of strengths.

anced panel which represented both the diverse backgrounds of those involved and the variance of possible evaluations.

Completion of the questionnaire entailed pairwise comparison of individual SWOT factors with other factors in the same SWOT category (S_a to S_b, etc.), as well as subsequent cross-category comparison (S to W, S to O, etc.). Figure 1 exemplifies pairwise comparison for the category "strengths".

All the comparisons were prioritized on the basis of a 9-point scale, as recommended by Saaty (1986). For example, a 9:1 ratio means that factor a is much more important than factor b, while a ratio of 1:9 means that factor b is much more important than factor a. The even numbers were deliberately left out as intermediate steps. At the centre of the scale (1:1), factors were considered to be of equal importance.

Once all the factors were compared, the relative priority level p ($0<p<1$, $\sum_{i=1}^{n} pi=1$) for each of the SWOT factors in a group of n factors was computed as suggested by Saaty (1986). We first calculated the *local factor priority* – that is, the relative importance of each factor based on the average values of the expert comparisons of the factors within the same SWOT category. Secondly, we determined the *group priority* – that is, the relative importance of each of the respective SWOT categories. Finally, we multiplied the local factor priority by the respective group priority, resulting in the *global factor priority* for every individual SWOT factor.

In order to cross-check the consistency of the results, we calculated the consistency ratio (CR). The CR indicates the extent to which participants make consistent judgments (i.e., judgments that comply with the principle of transitivity). As suggested by Saaty (1986), a CR of ten percent or smaller is acceptable. If the CR does exceed ten percent, all or some of the comparisons must be repeated in order to resolve the inconsistencies of the pairwise comparison (Saaty 1977). In our analysis the CRs are less than 0.1, thus ensuring a sufficient degree of consistency among our respondents' assessments.

Note that not all possible SWOT factors can be considered for processing with AHP, since the number of necessary pairwise comparisons grows exponentially with each additional factor. Saaty (1980) suggests using only a small number of factors in order to keep pairwise comparisons to a manageable level. As mentioned above, we proceeded with three key factors in each SWOT category. We believe that the selection of factors, together with the use of expert judgment, lends considerable credence to the overall validity of the analysis and that it also serves to offer a systematic overview of PV technology in Austria, in terms of the shift from the niche to the regime level.

Results and Discussion

Strengths, Weaknesses, Opportunities and Threats

For our SWOT analysis we designed a questionnaire including three factors for every strength, weakness, opportunity and threat. The selected SWOT factors are summarized in table 1 (p. 44).

Furthermore, each SWOT section contained an open-format question enabling participants to make further suggestions. Experts mentioned as additional opportunities, for example, "photovoltaics combined with e-mobility" or "access to new markets and business models". In our opinion, both of these additional opportunities are already contained in the factor *O_c: high diversity of application*. Another argument named with respect to weaknesses ("quality management of the grid") was integrated into the factor *T_a: difficulties in maintaining grid stability*. "Hegemony of the energy providers", suggested as a further weakness, can simply be seen as further evidence of the desire for energy independence and was treated as such in the analysis (W_a). Additional factors mentioned by experts, but not covered by the selected SWOT factors, were "peacekeeping through PV" as an opportunity, and "dependence on raw materials" as a threat. Both suggestions can be seen as individual opinions of experts and were, therefore, not included. In general, the answers to the open questions were helpful in verifying and validating the final choice of SWOT factors.

Analytic Hierarchy Process Analysis

After the SWOT factors were weighted by experts, we used AHP to calculate the group, local and global priority scores (table 2, p. 45). Local priority scores display the relative importance of the individual factors within the same SWOT field. For example, they show the respective rankings of the strengths as assessed by the experts. The global priority scores represent relative importance across the SWOT matrix as a whole, for example, which factor with respect

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TABLE 1: Overview of the selected SWOT factors for photovoltaics technology (PV).

STRENGTHS (S) *What are the strengths of PV technology?*	WEAKNESSES (W) *What are the weaknesses of PV technology?*
S_a price reduction of modules and therefore competitive costs S_b sunlight as renewable resource, emission-free operation S_c flexible installation possible (e. g., size, building-integrated)	W_a with no ability to store energy, no autarky W_b no economic viability without subsidies W_c low and decreasing energy yield, over time
OPPORTUNITIES (O) *What external factors might support PV diffusion?*	**THREATS (T)** *What external factors might hinder PV diffusion?*
O_a increasing willingness to use decentralized solar energy O_b high support at all political levels O_c high diversity of application (e. g., new business models, solar shares)	T_a difficulties in maintaining grid stability T_b uncertainty regarding economic framework conditions T_c public resistance to new PV projects (e. g., large-scale stand-alone plants)

to all SWOT groups was weighted as highest. The group priority figures indicate expert opinion regarding the respective importance of the four SWOT fields, that is, which field was most or least important: strengths, weaknesses, opportunities or threats. In compliance with the AHP method, the values of the priorities are normed and thus are set between 0 and 1. All the values displayed were rounded to two decimal places.

The across-group examination (group priority) of the SWOT factors reveals that strengths are most influential, with a group weight score of 0.41. In descending order of relevance follow opportunities (0.28), weaknesses (0.19) and threats (0.12).

Turning to the respective values for specific factors in each SWOT category (local priority), the most significant strength is the price reduction of modules and therefore the competitiveness of costs (S_a) ($p=0.39$). The low economies of scale possible, together with the expected decline in production costs (and prices), are clearly a source of enormous potential for the PV industry, and greatly facilitate decentralization of energy generation. Continuing with the ranking of strengths, it was found that sunlight as renewable resource, emission-free operation (S_b) was placed second ($p=0.31$). Photovoltaics is obviously seen as being an environmentally friendly and sustainable mode of producing electricity (although, in the strict sense of the word, sunlight is not really renewable). Flexibility of installation (S_c) is relatively important in terms of global priorities, even though it receives the lowest priority in the group of strengths. Modular construction methods make it easy to adjust PV installations to the application at hand (e. g., households, solar parks, building facades, or small-scale applications in traffic lights) (Koinegg et al. 2013).

As our analysis reveals, the most serious weakness is associated with the fact that autarky cannot be achieved in the absence of suitable storage possibilities (W_a) ($p=0.51$). While this may be interpreted in several different ways, we focused on energy independency at the user level (households, companies, regions, etc.), as recent studies (e. g., Brudermann et al. 2013, Schmidt et al. 2012) suggest that independency from electricity providers is an important aspect in the considerations of potential adopters. The meaningfulness of autarky on household level is unquestionably subject to controversies. However, the desire for individual independency by using PV electricity generation is a clear force pushing strongly towards the development of economically and ecologically feasible storage solutions (e. g., Beaudin et al. 2010). Other weaknesses, such as the relatively low and decreasing energy yield (W_c) or the dependence on subsidies (W_b), are considered to be rather insignificant.

In the category of opportunities, the highest-rated factor is the observation that willingness to use decentralized solar energy (O_a) is on the rise in general ($p=0.48$). Photovoltaics has become a well-accepted technology. The next important opportunity found in our analysis relates to the general level of acceptance and support for photovoltaics. Although from time to time critical voices may be raised, especially concerning the amount and availability of public subsidies, the experts' opinion reflects a rather high degree of support for photovoltaics at all political levels (O_b) ($p=0.34$). Present and future governmental policies will clearly have an influence on the further development of the technology and on the adoption and diffusion process (O_c).

Concerning the threats, the difficulties present in maintaining grid stability (T_a) are seen as the most significant factor ($p=0.42$). It is well-known, for example, that electricity generation based on wind and solar power is subject to enormous fluctuations. Overcoming the uncertainties perceived as inherent in such generation technologies is a major challenge in any move towards greater energy sustainability, for both users and producers (Neukirch 2013). In contrast, the public resistance to new PV projects (T_c), which may sometimes be observed, is seen as being of relatively little importance within this group ($p=0.30$). Compared to the other SWOT categories, threats are not considered as being very important at all. Various policies supporting information dissemination or promoting public participation are usually sufficient to convince people that their concerns are being taken seriously (Raven et al. 2009, Walker 2008). Participatory approaches such as the adoption of photovoltaics in community renewables, or in the form of citizen power plants, focus on involving people in the planning process or in easing their transition towards co-ownership or purchase (Musall and Kuik 2011, Renn et al. 2013). That such efforts are frequently successful, does not mean, however, that further integration and expansion of renewables in existing grid systems will never meet with public protest.

The global AHP rankings are illustrated in figure 2 (p. 46). The values in each group are given in absolute terms. The global priorities for the individual factors are given by the points on the lines.

TABLE 2: Final weight scores of the SWOT factors, consisting of the group, local and global priority. Ranks are given in parentheses.

SWOT factors	consistency ratio (CR) (%)	group priority	local priority	global priority
STRENGTHS (S)	0.04	0.41		
S_a price reduction of modules and therefore competitive costs [a]			0.39 (1.)	0.16 (1.)
S_b sunlight as renewable resource, emission-free operation			0.31 (2.)	0.13 (3.)
S_c flexible installation possible			0.30 (3.)	0.12 (4.)
WEAKNESSES (W)	1.34	0.19		
W_a with no ability to store energy, no autarky [b]			0.51 (1.)	0.10 (5.)
W_b no economic viability without subsidies			0.29 (2.)	0.06 (7.)
W_c low and decreasing energy yield, over time			0.20 (3.)	0.04 (10.)
OPPORTUNITIES (O)	0.47	0.28		
O_a increasing willingness to use decentralized solar energy [b]			0.48 (1.)	0.13 (2.)
O_b high support at all political levels			0.34 (2.)	0.09 (6.)
O_c high diversity of application			0.19 (3.)	0.05 (8.)
THREATS (T)	1.14	0.12		
T_a difficulties in maintaining grid stability [b]			0.42 (1.)	0.05 (9.)
T_b uncertainty regarding economic framework conditions			0.29 (3.)	0.04 (12.)
T_c public resistance to new PV projects			0.30 (2.)	0.04 (11.)

CR (comparison between SWOT groups) = 2.92 %

a factor with highest local and global priority | b factor with highest local priority in respective SWOT field

According to figure 2, experts evaluate the positive factors (strengths and opportunities) associated with PV technology as more important than the negative ones (weaknesses and threats). This finding confirms that the experts surveyed believe photovoltaics to be an increasingly promising technology.

Following the global ranking of priorities, the spread of PV technology is still largely driven by economic considerations. Module prices have decreased rapidly in recent years, making photovoltaics much more competitive and affordable than it used to be. This development is reflected directly in adoption and diffusion rates for the new technology.

While the main positive aspects in undertaking such a transition relate to social and economic factors, the respective challenges appear to be of a technical nature. This is in line with previous research (e.g., Halász and Malachi 2014, Khan and Pervaiz 2013). The most prominent weakness is the difficulty of providing suitable storage of PV electricity, especially at the household level. The question of whether autarky at the household level is desirable or reasonable is frequently raised by potential PV adopters (Brudermann et al. 2013, Schmidt et al. 2012), and is therefore a possible barrier in PV diffusion. However, over the long-term, there seems to be little doubt that these challenges will be overcome (e.g., via the use of smart grids, various electricity storage solutions).

Promising Aspects for Photovoltaics

This paper discusses the factors that play a role in a potential transition of photovoltaics from a niche to a regime technology in Austria's energy system. The usage of the SWOT-AHP hybrid offers a suitable tool for weighting the importance of relevant factors, and for identifying possible key elements for a possible regime shift. Applying such a method helps to systematically order the key factors in PV diffusion. Thus, the results of this study contribute to a better and more systematic understanding of the transition factors and help identify the circumstances that are most influential in allowing photovoltaics to act as a driver in the transition towards an energy system based on renewables.

The present study suggests rather bright prospects for PV technology. Positive factors, that is, strengths and opportunities in SWOT terminology, dominate over negative factors, that is, weaknesses and threats. In our opinion current circumstances appear to be particularly beneficial with respect to photovoltaics, and are thus a main driver behind a potential regime shift in the energy sector. The ongoing technological progress in PV technology and the associated continuous fall in costs and/or increase in efficiency are certainly a key factor. A continuation of this trend will ultimately entail full independence from current subsidies. This release from subsidies is likely to be a prerequisite in enabling photovoltaics to gain momentum in escaping from the niche level and to its becoming an established socio-technical regime. The fact that small PV plants are not much less cost efficient than large ones provides an additional advantage in the spread of the new technology since it corresponds closely to the desire and willingness among end users for decentralized solar energy production and consumption (i.e., households as "prosumers").

A process of transition entails change in the key elements – technological, institutional and social (network) – constituting the environment and the regime (Raven 2007). In Austria (as elsewhere), electricity regimes have largely supported the development of large power plants operated by local energy providers. It is only since the 1970s that such developments have been increasingly criticized and alternatives sought. Consequently, innovations occurring in market niches have gained significance in driving the process of energy transition. With regard to the role of photovoltaics in Austria's energy transition, the results of our study suggest

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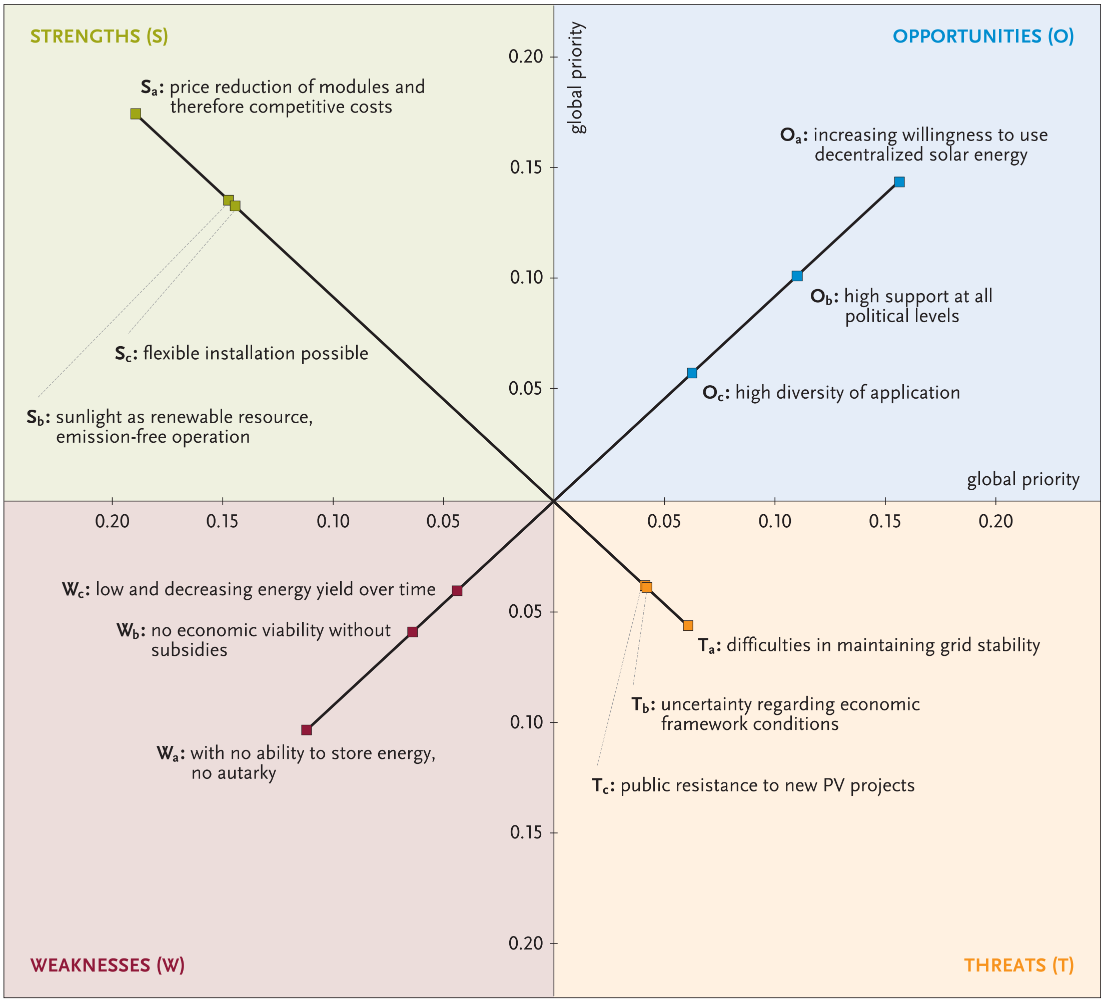
FIGURE 2: Graphical representation of global priority of SWOT factors, showing the importance of relevant factors for further diffusion of PV technology and for a possible regime shift. The coordinates of some data points are slightly different from the rounded numbers displayed in table 2, as the chart is based on the original values.



to place additional emphasis on regime elements such as "infrastructure" since this can serve to overcome grid challenges. In order to further maintain both political support and high public willingness in the use of decentralized PV energy, potential strategies need to focus on the relevant social change and network effects. For example, the development of a shared public vision concerning our future energy regime can help to open up new pathways in energy technology. This serves to make technologies such as PV electricity generation more competitive and thus facilitates their integration into the existing dominant energy regime.

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