Does Transmission Technology Influence Acceptance of Overhead Power Lines? An Empirical Study

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Abstract: For the transmission of electricity across long distances, high voltage direct current (DC) transmission is discussed in Germany as an alternative to the currently used alternating current (AC) as it is more efficient for these distances. Changes in energy infrastructure are known to raise public awareness. However, little is known whether differences in transmission technology are relevant for the public and if so, to what extent. Two consecutive empirical studies were run in which acceptance towards transmission lines operated with DC in contrast to AC was explored. AC and DC power lines were not evaluated differently, yielding overall quite neutral ratings (Study 1) which might be due to a low information level in the public. A closer look (Study 2) showed that giving information on technical and design parameters of the transmission lines used for either AC or DC technology also did not change attitudes substantially. It is therefore concluded that transmission technology alone did not influence acceptance of power lines for the investigated sample. In addition, a need for more information on DC for high voltage transmission was identified. Further research is required on the influence of different power line layout of AC and DC on acceptance.

1 INTRODUCTION

In Germany, the goal to have a quota of at least 80% of renewable energies in electricity production until 2050 (*German Renewable Energies Act (EEG)*, 2014) poses challenges to the current grid, not only with respect to the grid structure itself but also to the geography of transmission networks. The distributed electricity production from renewable energies and its far-off consumption requires a grid that is capable of long-distance transmission.

Electrical transmission grids allow highly efficient transporting of electrical energy over long distances. But high-voltage alternating current transmission (HVAC) suffers from losses due to reactive-power demand (which requires reactive VAR compensation or over-designing the infrastructure) or skin effects, for example. These losses can be compensated if transmission lines are operated with high-voltage direct current (HVDC). HVDC, however, has the disadvantage that power-electronic converters are required to transform AC into DC and then DC back into AC, which causes investment costs and losses. Also, HVDC converter stations are bigger than transformers and auxiliary equipment may be required for HVAC transmission. HVDC is nonetheless superior to HVAC for long transmission lengths, especially for cable grids. Because transmission lines operated with AC technology have faced considerable public opposition in the past (Cotton and Devine-Wright, 2013; Zaunbrecher et al., 2015), the question arises if the integration of DC technology into the grid will face the same opposition. From a technology acceptance point of view, it is unclear which outcome and argumentation line residents would follow. Basically, different outcomes might be assumed: One possibility is that changes towards DC technology might achieve greater acceptance among residents, as it is more efficient for long distance transfer. Besides, electro-magnetic fields (EMF) do not occur in DC transmission and, on top, transmission lines operated with DC are more compact (doubling the power as compared to AC transmission, Clerici et al. (1991)) thus reducing the visual impact on the landscape. This outcome would

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reflect a quite mature understanding among laypeople. The second outcome could relate to a more negative attitude, referring to residents' general aloofness to infrastructure changes in terms of supergrids (Van Hertem and Ghandhari, 2010). In this context it is pivotal to learn which features of the infrastructure receive public attention. For electricity grids it has been shown (Devine-Wright et al., 2010) that elements belonging to a grid and which are not visible are rarely associated with it, as people rather rely on concrete objects such as fuses, cables, etc. when describing their ideas of electricity transmission. It is thus possible that for the acceptance of transmission lines, from a layperson's point of view, transmission type does not play a decisive role, because it refers to a rather abstract concept and, furthermore, is hardly visible at all.

For a successful gird expansion, adequate communication is vital (Apt and Fischhoff, 2006). Hence, it is necessary to know what matters, what is relevant to residents, and which information they need to participate in the dialogue about grid expansion. In this context, a basic question is if information and knowledge play a mediating role for acceptance. First of all, it is therefore essential to come to an understanding how informed the general public is about AC and DC transmission. Second, it should be investigated whether a change of transmission technology changes the attitude and acceptance towards transmission lines. Third, the question will be answered in how far information on the two technologies influences preferences for one or the other technology. For these purposes, two empirical studies were conducted in which the role of the transmission technology for the acceptance of power lines (Study 1) and the relation between level of information and other, attitudinal factors about the technologies, and social acceptance (Study 2) is investigated.

2 ELECTRICITY TRANSMISSION

The high efficiency of transmission grids that transport electrical energy over long distances is important to ensure the economic operation of the system. Thus, the operation voltage is increased to reduce the current and hence the ohmic losses due to resistance of the conductor. In conventional systems operated with AC, transformers are used to step up the voltage level for transmission. Afterwards, overhead lines (OHL) or power cables are used for energy transport. However, limitations are given due to the reactive power demand of OHL and power cables ("ABB review Special Report: 60 years of HVDC," 2014). Reactive power results from alternating electromagnetic fields that occur if OHL and power cables are operated with AC and increases with transmission length. Hence, the conductor (OHL or cable) does not only have to carry the active current that contributes to the power transfer but also the additional reactive current. This reactive current also loads the conductor and causes ohmic losses. Furthermore, the reactive current reduces the active power-transfer capability of the OHL and power cable ("ABB review Special Report: 60 years of HVDC," 2014; Song-Manguelle, et al., 2013). The maximum length of OHL and especially of power cables to transport a certain power is limited due to the reactive power demand when the system is operated with AC. Since power cables have a higher reactive power demand than OHL, the maximum possible AC transmission length is shorter. However, the reactive power demand of OHL and power cables can be reduced by compensation measures. But these additional components cause additional investment costs and losses. If DC is used instead of AC, the maximum transmission length is not limited since the reactive power demand of OHL and power cables vanishes.

The omission of reactive power is a great advantage of DC transmission systems. In this case, the conductive material is not unnecessarily loaded with reactive current. Furthermore, the utilization of the conductor is improved since the skin effect, causing an unequal current density in the cross-section of the wire and leading to higher ohmic losses, disappears with DC. Hence, ohmic losses are reduced and the efficiency of the OHL and power cable is improved in this case. Today, HVDC transmission systems (Flourentzou et al., 2009; Bahrman and Johnson, 2007) are embedded in an existing AC grid infrastructure. Therefore, power-electronic converters have to be applied to convert AC into DC and vice versa (Figure 1).

Since the power-electronic converters lead to additional investment costs and power loss, HVDC systems compete with HVAC systems with increasing transmission length.

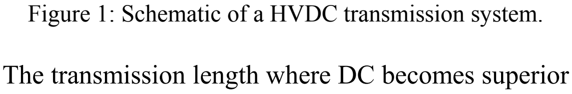

Figure 1: Schematic of a HVDC transmission system.

The transmission length where DC becomes superior to AC depends on whether OHL or power cables are applied. Since the reactive power demand of power cables is higher than of OHL, HVDC becomes more economical for transmission lengths above 50 – 80 km (Glasdam et al., 2012; Lundberg, 2006), whereas transmission systems based on OHL are more efficient with AC for transmission lengths up to 500 – 800 km (Meah and Ula, 2007). However, due to decreasing costs for power-electronic converters (De Doncker, 2014), a further reduction of the break-even is expected. Also, DC transmission differs from AC in the infrastructure needed in two aspects:

On the one hand, the HVDC converter stations that impact the characteristic landscape are larger than transformers needed for AC. For example, a 1,200 MW converter station has a footprint of 120 x 150 m^2 and is 20 m high ("ABB review Special Report: 60 years of HVDC," 2014). On the other hand, since transport capacities of DC transmission systems are not wasted for reactive power, the size of OHL and power cable routes can be reduced. It is shown in Figure 2 that the space requirement of HVDC OHL can be halved compared with HVAC. If power cables are applied, pylons do not even impact the scenery.

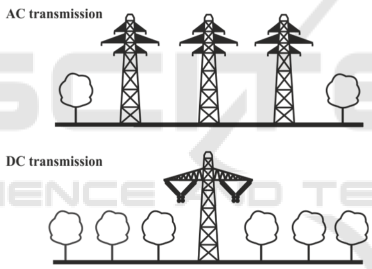

Figure 2: Space requirement of AC and DC overhead lines ("ABB review Special Report: 60 years of HVDC," 2014).

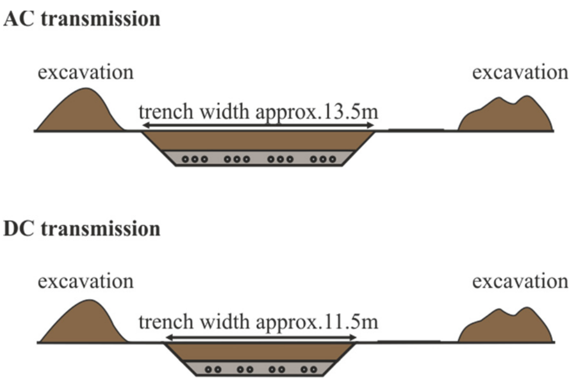

Figure 3: Exemplary trench width for power-cable transmission (Hofmann, 2015).

Furthermore, due to the lower number of power cables and higher power capability with DC, the width of the trenches can be reduced as shown exemplarily in Figure 3.

The characteristics discussed so far are relevant for grid expansion and modification. The question remains if they are also relevant from an acceptance point of view, especially from the perspective of laypeople, as they represent the majority of residents and form public acceptance.

3 FACTORS INFLUENCING ACCEPTANCE OF TRANSMISSION LINES

From a social science point of view, energy infrastructure poses challenges to existing technology acceptance models like, for example, TAM (Venkatesh and Bala, 2008) and UTAUT (Venkatesh et al., 2003) for various reasons: Infrastructure changes influence space and landscape to a great extent, thus being subject to, e.g., influences of place attachment (Devine-Wright, 2013). They represent systems which are a lot more abstract, thus more complex to grasp and to gain an understanding of (Cohen et al., 2014; Kowalewski et al., 2014). In addition, especially in the context of renewable energies and connected grid expansion, acceptance of the infrastructure is often impacted by attitudes and personal norms (Huijts et al., 2012), such as risks and benefits, positive and negative attitudes towards the technology, trust, but also the assumed costs for infrastructure changes or procedural and distributive fairness.

With the turn towards renewable energies, social acceptance of the infrastructure needed to achieve the ambitious goals has therefore become the focus of a large strand of research. It has become clear that without sufficient support by the public, it will be very difficult to put the energy reconversion ("Energiewende") into practice (Wüstenhagen et al., 2007). However, even though this might be essential from a technical point of view, convincing the public in terms of marketing issues might not be the most successful way. Rather, understanding the nature of solicitudes and the specificity of argumentation patterns in line with a persons' cognitive concept about a technology is essential in order to develop individually-tailored information or communication strategies.

As has been pointed out, the extension or modification of the grid plays a vital part in the energy reconversion, and therefore, public attitudes to transmission lines have come into focus in the recent public and scientific discussion.

When a new transmission line is planned, in some cases affected residents protested and formed civil action groups. These actions delayed grid expansion over many decades. Arguments by opposing groups often state that transmission lines might spoil the landscape (Atkinson, 2006).

A recent study (Zaunbrecher et al., 2015) revealed that the relative location of the pylon and the distance to people's own home is of vital importance for acceptance and the willingness to tolerate electricity pylons near residents area of living. Interestingly, health consequences are evaluated much more important than the availability of compensation payments, corroborating previous findings (Jay, 2007) which shows that acceptance cannot simply be "bought". Consequences for nature and health (Priestley and Evans, 1996), notably by electromagnetic fields (EMF), is another argument against transmission lines that is frequently cited by residents (Cotton and Devine-Wright, 2013). According to Claassen et al. (2016), what is most important concerning this topic is a clear communication about the current scientific uncertainty about health risks caused by EMF, as well as raising awareness about exposure to EMF not only from transmission lines, but also from sources in daily life, so as to counterbalance the overestimation of EMF exposure from transmission lines. Connected to the issue of EMF and visual disamenities is the worry of a decrease of property values of adjacent houses (Furby et al., 1988).

In Germany, most of the high-voltage transmission lines are operated with AC. However, DC is currently being discussed as an alternative due to a higher effectiveness for long-distance transfer. Because of the different characteristics, for example the number of power lines, it is of interest if social acceptance is influenced by a change of transmission technology. Little is known so far about this issue, which is also connected to the question if information levels and knowledge about grid technologies has an influence on acceptance. A number of studies have addressed public knowledge and knowledge of laypeople about transmission lines.

Aas et al. (2014) investigated perceived knowledge about electric power line systems and their operators across three countries, and found overall low familiarity. Besides, they found (although low) significant correlations between perceived familiarity and acceptance, calling for further investigation of the relation between knowledge, perceived familiarity and acceptance. The fact that there is little knowledge in the general public about the electricity network, its functionality and responsible institutions was also underlined by a further study in the UK, in which participants also sought other types of networks (railway, mobile communication) as references for comparison (Devine-Wright and Devine-Wright, 2009).

While participation has been identified as a means to create knowledge in the general public (Ciupuliga and Cuppen, 2013), a lack of information was found to be connected to negative feelings concerning the opportunity of locals to influence decision processes in the context of transmission line siting (Cotton and Devine-Wright, 2011).

Although transmission lines and their social acceptance have been researched in depth, and a variety of influential factors have been identified, ranging from design to social issues, technical specifications and their influence on acceptance have remained under-researched. The current study aims to shed some light on the role of transmission technology for acceptance of transmission lines by means of two empirical studies.

4 QUESTIONS ADDRESSED AND LOGIC OF EMPIRICAL PROCEDURE

AC and DC technology have not been addressed in contrast from a social science point of view in the context of the grid in any of the studies conducted so far. Investigating whether acceptance changes based on the transmission technology used is a pressing question for grid operators and electrical engineers concerned with the expansion of the grid. In this context, the social representation of electricity network technologies (Devine-Wright and Devine-Wright, 2009) comes into focus and the question if mental models of residents do differ with respect to the way electricity is transferred. It could very well be that respondents are indifferent towards the different technologies because of a lack of knowledge or because they simply do not care and focus more on infrastructure characteristics in terms of overhead transmission vs. underground cable.

In order to understand if acceptance differences can be expected, two empirical studies were executed. In the first study, no further information about AC and DC technologies was given, thus capturing the unbiased evaluation and acceptance of transmission lines operated with either of the two technologies. In the second study, in contrast, acceptance of AC and DC transmission was measured after information on both technologies was given to the participants.

5 STUDY 1: ACCEPTANCE OF AC VS. DC TRANSMISSION LINES

In study 1, the goal was to analyze how the acceptance of a transmission line would change if instead of AC, DC technology would be used. In this first study, no prior information about the technologies was given to the participants as to investigate the acceptance of the two technologies based on their current state of knowledge, without being influenced by additional information. This exploratory procedure allowed – beyond capturing unbiased public view on AC and DC technologies - to assess the current state of knowledge on both technologies in the general public.

5.1 Methodology

In order to reach a broad range of participants, an online questionnaire was designed and distributed via social networks and online discussion forums. The questionnaire contained three major parts. In the first part, generic demographic information of the participants was gathered (age, gender, area of living, and highest educational degree).

The second part addressed the technical expertise, including knowledge about electricity and participants' personal attitude towards technologies (ATT) in general. Participants were asked to indicate (on a six-point scale) from "expert" to "layperson" how they would classify themselves in the fields of electricity and technology in general. They also answered five questions on attitude towards technology (ATT) which were based on Karrer et al. (2009) but formulated more generally, because they were used in the context of technology infrastructure rather than technical devices in this study.

- *"I am interested in technology"*
- *"Using technology is easy for me"*
- *"I don't trust technology in general"*
- *"I have fun using technology"*
- *"I avoid technology whenever possible"*

For each participant, a mean score for ATT was calculated for which negatively formulated items were recoded (Cronbach's alpha (CA) =0.85). High scores thus indicated positive attitude towards technology. While the first two parts of the study were used to gain an understanding of the sample, in the third part, the knowledge and acceptance of AC and DC transmission lines was in the focus. The perceived knowledge and information on AC and DC technology as well as on grid expansion was assessed using the following items:

- *"I feel well informed about AC technology"*
- *"I feel well informed about DC technology"*
- *"I feel well informed about the grid expansion in general"*
- *"I would like to know more about AC"*
- *"I would like to know more about DC"*

Items were answered on a 6-point Likert scale (1= do not agree at all, 6= fully agree).

Further eight items were given to measure acceptance towards AC transmission lines, five of which referred to characteristics of power lines (CA=0.81) and three to attitude towards them (CA=0.86), (cf. Figures 3 and 4). The same set of items was repeated in a scenario in which DC technology was used (CA characteristics=0.74, CA attitudes=0.77). The items were selected to represent the most prevailing arguments in the discussion on pylon acceptance, such as health concerns (Jay, 2007; Claassen et al., 2012) and impact on landscape (Navrud et al., 2008; Soini et al., 2011), as well as items on potential for protest and general acceptance. All questions were answered on a 6-point Likert scale (1= do not agree at all, 6= fully agree), unless indicated otherwise.

For analysis, the statistical software SPSS was used. The confidence level was set at 5%. Not all participants filled out the questionnaire completely, thus pairwise exclusion of missing values was used when necessary.

5.2 Sample

Overall, 109 participants fully completed the questionnaire and were included in statistical analyses (largely incomplete answers were excluded).

Demographic information: 47% of the participants were female, 53% male. The mean age was 33.2 years (SD=15.6), age ranged from 18 to 81 years. 54% had completed university education, further 28% had obtained a qualification for university entrance. 45% lived in a city center, 23% in the outskirts, and 32% in a village. 11.9% lived near transmission lines. 12.8% of the participants had a technically-oriented occupation, 34.5% a non-technical occupation (51.5% could not be specified, as respondents had answered generically, e.g., "student" or "self-employed," 9.2% did not disclose this information).

Technology expertise: On a scale of 1

(layperson) to 6 (expert), 59.6% classified themselves as “electricity laypeople,” while only one participant reported to be an “electricity expert.” Five participants (4.6%) found they were “technical experts”, compared to 32 (29.6%) who found they were “technical laypeople”. Mean score for ATT was 4.4 (SD=1.0, Max: 6). Over all, the sample under study had a rather positive attitude towards technologies, but was not too confident about their expertise regarding electricity.

5.3 Results

First, results of the level of information and interest in AC and DC technology are presented. Then, the acceptance regarding the “AC transmission line” and “DC transmission line” is compared.

Information and interest in AC und DC Technology:
The subjective level of information was equally low for both AC and DC transmission (both: M=2.4, SD=1.4), which was also true for perceived level of information on the expansion of the grid (M=2.4, SD=1.3). Participants expressed their interest in more information on the two technologies (both: AC: M=4.0, SD=1.3).

Acceptance of AC vs. DC technology:
In a next step, from the eight items measuring acceptance of AC and DC transmission lines, means were calculated for the factors “attitude” and “ascribed characteristics” for both AC and DC technology (negatively worded items included in reversed order). Results are displayed in Table 1. It can be seen that attitudes and ascribed characteristics were the very same in the AC and DC scenario.

Table 1: Means for attitude towards DC and AC transmission lines and means for ascribed characteristics.

	DC	AC
Attitudes	M=4.0 (SD=1.1)	M=4.0 (SD=1.2)
Characteristics ascribed	M=3.7 (SD=0.9)	M=3.7 (SD=1.0)

By comparing the agreement to the statements in AC and DC settings (using paired samples t-tests), it was examined whether the acceptance for transmission lines operated with AC or DC technologies was different. Outcomes are given in Figure 4 and 5. Two things are noticeable: One is that AC and DC technologies are not evaluated differently: Transmission lines do not raise strong acceptance concerns, but evoke a neutral if not indifferent public opinion.

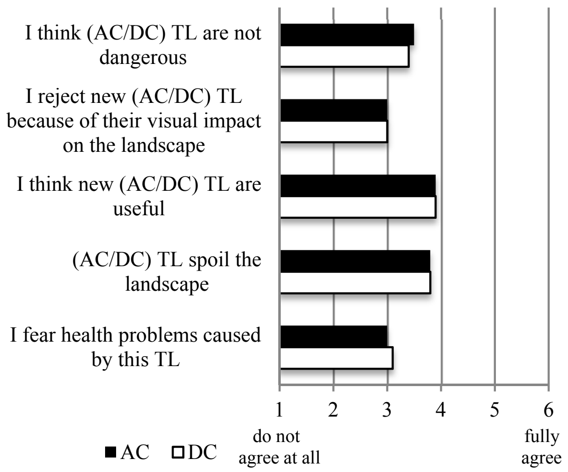

Figure 4: Ascribed characteristics to AC and DC transmission lines.

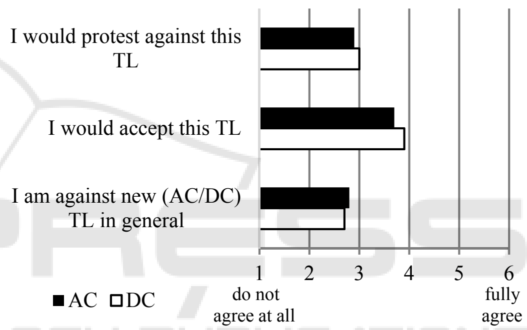

Figure 5: Attitude towards AC and DC transmission lines.

The second point refers to the bias towards the middle of the scale of participants’ answers here. Most of the answers were oriented towards the middle of the scale, with no clear opinion towards the transmission lines operated with either of the two technologies.

From these results, it is inferred that transmission technology does not change attitudes towards or perceptions of transmission lines. However, it still remained unclear whether the indecisiveness was the result of lack of knowledge or of indifference towards the transmission mode.

Further analyses into attitudinal factors on expertise and their relationship to attitude and perception were conducted by using Spearman correlations to gain insights into other possible influential factors on acceptance. Table 2 shows the Spearman correlations between attributes of technical expertise and attitude towards and acceptance of AC and DC transmission lines. It was found that especially ATT correlated weakly but significantly and consistently with all factors, suggesting an increase in acceptance of AC and DC transmission lines with increasingly positive attitudes towards technology.

Table 2: Correlations between attributes of technical expertise and perception of AC and DC transmission lines in study 1. *p≤ 0.05, **p≤ 0.01, ***p≤ 0.001.

	DC attitude	AC attitude	DC charac.	AC charac.
ATT	0.35*** (n=109)	0.36*** (n=109)	0.36*** (n=109)	0.23* (n=109)
Elec. expert	0.28*** (n=108)	0.18 (n=108)	0.30*** (n=108)	0.07 (n=108)
Techn. expert	0.28** (n=108)	0.25** (n=108)	0.32*** (n=108)	0.17 (n=108)
DC informed	0.22* (n=109)	0.19 (n=109)	0.24* (n=109)	0.09 (n=109)
AC informed	0.22* (n=109)	0.18 (n=109)	0.24* (n=109)	0.08 (n=109)

5.4 Summary

The results of study 1 indicated that incidentally selected laypeople participants do not differ in their attitude towards transmission lines operated with AC or DC technology. As the overall level of information and expertise on the topic had been quite low in the sample, this could well be an effect of a lack of information. Technical expertise and participants' attitudes towards technology on the other hand, were positively related to acceptance and perception. In order to gain further insights into the role of the level of information and expertise for the perception of AC and DC transmission, a second study was conducted.

6 STUDY 2: ROLE OF INFORMATION ON THE ACCPETANCE OF AC VS. DC TRANSMISSION LINES

In study 2, the objective was to examine if participants differed in their acceptance of AC and DC transmission lines when they are informed about the technical characteristics of both technologies. The study design therefore included a section with detailed information on both technologies before participants were asked the set of items about AC and DC transmission lines. It was also taken care that the second study was distributed more frequently among technically oriented persons (by education, occupation, etc.), to investigate further the relationship between general technology expertise and transmission technology perception.

6.1 Methodology

For reasons of comparison, the questionnaire used was that of study 1, with some alterations regarding the information given on the technologies. In contrast to study 1, the second survey contained a text with information about the two kinds of electricity transmission. The text addressed technical, financial, environmental, and health issues and how the two technologies differed in those respects and was written in a non-technical style:

Technology: So far, the transmission of energy using alternating current (AC) was the only option, because the technology did not offer the possibility to increase the current of direct current (DC) to such an extent that transmission was possible. Nowadays, however, DC and AC converters can convert electricity in a suitable form and feed it into the grid. One of the advantages of DC HVL is the reduced number of power lines (2 instead of 3), thus saving material. Besides, transmission via DC is more efficient from 600km onwards, as there are no losses like in AC transmission.

Health: In contrast to AC, transmission lines operated with DC do not create an electro-magnetic field, only a magnetic field which is similar to that of the earth. No medical studies have to date confirmed that there are health risks to be expected from fields induced by AC, but should this be an issue in future, only lines operated with AC would be subject to debate.

Costs: Transmission via AC is economically efficient up to 600 km. From 600 km onwards, DC is more economically efficient in transport, as the energy losses are lower.

The validity and quality of the information was checked by experts prior to the study. It was taken care that both AC and DC were presented in an objective manner. A pre-test with laypeople (n=8) was performed to ensure comprehensibility of the information. After the information text in the questionnaire, participants were again presented first with the scenario with DC, then with AC technology, and asked for their agreement to various statements (items see Study 1).

Subjective level of information was not surveyed out of methodological reasons, as this could be distorted by the information text.

6.2 Sample

147 participants were recruited from various sources, including social networks and online discussion groups. 15 had ended the questionnaire after the first few questions, therefore they were excluded from analysis. Answers of 132 participants were finally taken into account. Of those, 34.1% were female, 65.9% male. The mean age was 33.2 years (SD=12.1). 47.7% held a university degree, further 29.5% a qualification for university entrance. 53% lived in a city center, 26.5% in the outskirts of a city, and 20.5% in a village. 18.9% reported to live within view of a power line. 18.2% reported to be "electricity laypeople," while 9 (6.8%) reported to be electricity experts. 27.3% estimated themselves to be "technical experts" (compared to 3.0% technical laypeople).

Compared to study 1, the sample included more male participants and felt more technically knowledgeable which was directly related (ANOVAs with gender as independent variable: electricity level of expertise: $F(1,117)=45.77, p\leq 0.01$, technical level of expertise: $F(1,117)= 57.92$, $p\leq 0.01$). 25% of the sample had a technical occupation, 15.2% a non-technical (55.3% could not be categorized, 4.5% missing answers). The mean score for ATT was M=5.2 (SD=0.8), thus markedly higher than in study 1.

6.3 Results

First, overall scores on attitude and ascribed characteristics were calculated (Table 3).

Table 3: Means for attitude towards DC and AC transmission lines and means for ascribed characteristics.

	DC	AC
Attitude	M=4.5 (SD=1.0)	M=4.4 (SD=1.1)
Characteristics ascribed	M=4.2 (SD=0.9)	M=4.0 (SD=0.9)

Paired samples t-tests were performed for the single items to investigate possible differences between the AC and the DC scenario (Figures 6 and 7).

On a descriptive level, compared to study 1, answers showed more extreme values, i.e., were more positive on the positive items and more negative on the negative items, which overall reflects a more welcoming attitude towards transmission lines in this sample.

It was found that for three items, answers differed significantly depending on whether they were presented in an AC or DC scenario: Perceived usefulness for DC was evaluated significantly higher

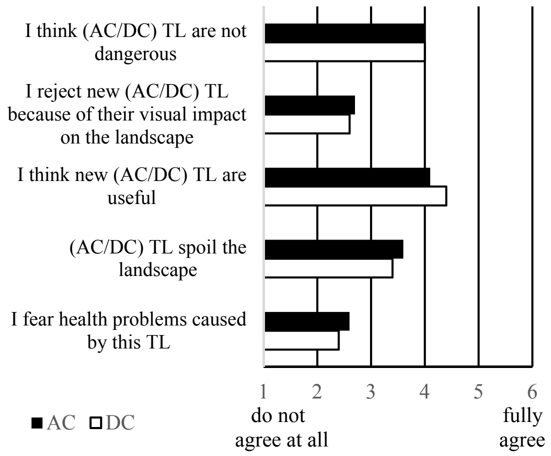

Figure 6: Ascribed characteristics to AC and DC transmission lines.

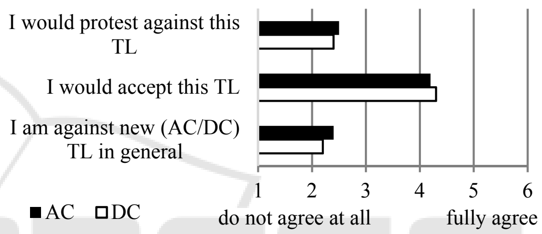

Figure 7: Attitude towards AC and DC transmission lines.

than for AC (n=114, T=-2.92, $p\leq 0.01$, $r^2=0.07$), DC was perceived to spoil the landscape to a significantly lesser extent than AC (n=115, T=2.07, $p\leq 0.05$, $r^2=0.04$), and participants were less scared of health problems caused by DC than by AC (n=116, T=2.81, $p\leq 0.01$, r2=0.06) though effect sizes were small (J. Cohen, 1988).

In a next step, attributes of technical expertise were again correlated with attitude and characteristics ascribed to AC and DC to analyze if the relationship between technical expertise and perception, which was found in study 1, also holds for study 2 (Table 4). After this, we analysed if differences in perception of AC and DC occur because of the information text which was given to the participants or, rather, because of the level of technical expertise. To this end, the sample was split into an expert group and a laypeople group. Experts were defined as participants who had an ATT score of 6 and/or classified themselves as technology experts (=6) and/or as electricity experts (=6). Using this classification, 45 participants were categorized as experts, 76 as laypeople (11 participants could not be classified due to missing data).

Paired samples t-tests for both groups revealed that for experts no significant differences between the AC and the DC setting occurred. Laypeople, in contrast, perceived possible health risks of DC significantly lower than of AC transmission lines ($T(1,72)=2.22$, $p \leq 0.05$, $r^2=0.05$) and also found them significantly more useful ($T(1,71)=-2.70$, $p \leq 0.01$, $r^2=0.09$). The split according to expertise thus indicated that the differences in acceptance scores in the overall sample are mainly due to the evaluation of laypeople.

Table 4: Spearman correlations between attributes of technical expertise and perception of AC and DC transmission lines in study 2. *p≤ 0.05, **p≤ 0.01, ***p≤ 0.001.

	DC Attitude	AC Attitude	DC Charac.	AC Charac.
ATT	0.14 (n=116)	0.12 (n=125)	0.26*** (n=116)	0.23* (n=125)
Elec. Expert	0.25*** (n=116)	0.24*** (n=118)	0.26*** (n=116)	0.3*** (n=118)
Techn. Expert	0.25*** (n=116)	0.24*** (n=118)	0.26*** (n=116)	0.3*** (n=118)

6.4 Summary

Study 2 validated the findings of study 1. For experts, transmission technology did not influence attitudes or ascribed characteristics towards transmission lines. For laypeople, there was a small difference in favour of DC for perceived health risks and usefulness. Thus, in spite of the additional information which was given to the participants, the attitudes towards transmission lines did not reveal fundamental differences but showed a quite solid positive perception towards transmission lines operated with AC or DC technology.

Correlation analyses revealed that expertise was in fact a prominent variable. Participants with a high technology and electricity expertise had more positive perceptions and attitudes about transmission lines in general (not differing between AC and DC). In contrast, the general attitudes toward technology (ATT) showed a lower prediction power compared to study 1.

7 DISCUSSION

In this paper, we introduce two empirical studies concerned with the question if different transmission technologies – AC and DC- are evaluated differently with respect to public perception and acceptance. The first study addressed a quite uninformed incidental sample of participants of a wide age range in order to capture an unbiased acceptance profile. In the second study, technical information about health, costs and effectiveness of both technologies was presented prior to the acceptance evaluation. Also, further insights about effects of expertise on acceptance were given.

It was shown that participants did not differ significantly in their opinion about AC and DC transmission lines when relying only on their knowledge about the two technologies at the time of the survey (Study 1). In study 2, it was evident that even when detailed information was given on the two technologies, only small differences in preference for the two technologies were detected for the overall sample (for usefulness, effect on landscape and perceived health risks).

Overall it was clearly revealed that transmission technology in this context does not influence perception and acceptance. In study 1, answers were very balanced, indicating a rather indecisive attitude towards the topic and in assessing characteristics. This would support the hypothesis that the effects, which had to be evaluated in the context of different transmission technologies, were not easily accessible for the majority of participants, because the framing in the context of transmission technology might have been too abstract (Devine-Wright et al., 2010). This could also be an effect of the relatively small number of participants who reported to live within view of a transmission line; further research is thus needed in actual case-study scenarios. The result that no difference was found should therefore be treated with caution, as it does not mean that this will be true for every group.

It is noteworthy that those items for which significant differences were detected in study 2 refer to specific evidence given in the information text and that they refer to characteristics of the transmission line rather than people's attitude towards the transmission line (such as reject, accept, protest, etc.). It is thus likely that the small but significant effects are a direct result of the information given in the info text. They might even have biased participants towards DC, as DC was more favourable concerning the factors presented in the information text.

Because the sample still was quite small, it could also be the case that the effects did not show yet and a bigger sample could lead to clearer results here. It would also be instructive in future studies to use information texts which focus on different aspects to find out if the new information is directly reflected in the acceptance pattern, as this has shown to be the case for information on risks (MacGregor et al., 1994). Nevertheless, the effect sizes are quite small (Cohen, 1988) and therefore their practical importance is questionable. Further studies will be necessary to test and replicate these findings.

The instruction text did not disclose visualizations of different layouts of transmission lines due to different transmission technologies (like in Fig. 2 and 3), to avoid that participants focus on the visuals only and instead take a range of characteristics into account for their judgement. As it was shown that the transmission technology alone did not influence preference for power lines, further research should concentrate on preferences for power line design (thus indirectly reflecting transmission technology). The topic of overhead vs. underground power lines was already covered in several studies (McNair et al., 2011; Menges and Beyer, 2014; Navrud et al., 2008) as was that of pylon design (Devine-Wright and Batel, 2013; Atkinson et al., 2004), but the connection between transmission technology and power line layout (e.g., DC overhead power lines and AC overhead power lines) has not been studied from a social science point of view. This could be very useful in order to disclose underlying mental models between technology infrastructure and their appearance in the landscape. Methodologically, however, another instrument than a traditional survey seems to be appropriate. As the concurrent examination of design factors and infrastructure variations (layout, efficiency, exposure to EMF) as well as their interdependence is of interest and possible trade-offs between them, a conjoint study would yield insightful evidence into acceptance relevant factors, as applied in the context of, e.g., mobile phone base stations (Arning et al., 2014) or camera surveillance (Arning and Ziefle, 2015). It will then also be of interest to discuss acceptable locations for converter stations, which possibly are subject to similar concerns as locations for pylons (Zaunbrecher et al., 2015). The converter stations needed for DC transmission also present a trade-off that needs to be made between transmission lines with lower landscape impact and a larger basal area of additional components.

The studies conducted lead to the conclusion that there is a substantial lack of knowledge, on the one hand, but an interest in more information on grid expansion as well as AC and DC transmission, on the other hand. Furthermore, the studies support earlier findings (Aas et al., 2014; Owens, 2000) that low familiarity is related to low levels of acceptance. In our case, it was not so much the perceived knowledge about AC and DC transmission which correlated with acceptance (study 1) but expertise and confidence in the context of technology in general as well as electricity. These results indicate that the relation of knowledge and acceptance of transmission lines is a complex one that does not only involve knowledge directly related to the grid. Lienert et al., (2015), for example, found in a study in Switzerland that it is not only knowledge about the grid itself that is lacking, but also the role of the grid in the context of the energy transition. In their study, it was unclear to about half of the participants that there was a connection between grid expansion and the energy transition. Those who were aware of the relation showed a significantly more positive attitude towards HVL.

8 CONCLUSIONS

The success and acceptability of new transmission lines, irrespective of AC or DC technology, will largely depend on adequate information and communication concepts which allow for early participation (Jewell et al., 2009), for which it is vital to identify relevant attributes and influencing factors for acceptance. The studies presented add to future information and communication concepts by investigating the role of transmission technology for the acceptance of power lines. Overall, the studies had three major findings: First, transmission technology does not have a major influence on acceptance of transmission lines for the sample under study, even if specific information on AC and DC technology is given. Second, acceptance and perception are, however, positively influenced by general ATT and expertise. Third, there is a substantial lack of information of the general public on grid expansion and the future role and potential of DC for electricity transmission.

Although the hypothesis held true that a change from AC to DC did not substantially change attitudes of participants towards transmission lines in our sample, it could be well worth investigating into this topic further, as DC offers some advantages in aspects often debated in the context of power lines (no EMF, more compact lines, possibility to use underground cables).

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