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Modes of governance for municipal energy efficiency services — The case of LED street lighting in Germany

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ABSTRACT

Energy efficiency retrofits are often impeded by high perceived investment risks, long payback periods and a lack of skills. At the municipal level these issues are particularly pronounced as procuring, implementing, and managing retrofits can exceed existing municipal governance capacities. The diffusion of municipal LED street lighting as a replacement for conventional lighting serves as an example. This paper argues that technological (e.g. complexity and maturity), economic (e.g. selling services vs. products and financing costs), institutional (e.g. property situation and contracts) and competency barriers to retrofitting (e.g. lack of measurement capacity and qualified facilitators) translate into transaction costs. We develop a taxonomy of appropriate modes of municipal retrofitting governance based on transaction costs economics. The findings indicate that more market-based solutions, energy performance contracts in particular, can facilitate the procurement of innovative energy efficiency retrofitting solutions and associated investments among municipalities if neutral tenders, open-book accounting, municipal ownership and intermediary organisations allow municipalities to choose appropriate governance structures for particular technologies and retrofits.

1. Introduction

Energy efficiency is the cheapest and most effective way of addressing issues such as climate change energy security, rising energy prices and associated social implications such as fuel poverty (EC, 2014; IEA, 2014a, 2014b; IPCC, 2014). As a result of incomplete energy efficiency markets, investments in associated technologies remain below the optimal level (IEA, 2013). Consequently, the rate of adoption and diffusion is low because structures and incentives for application are missing (Jaffe et al., 2005; Schleich, 2009; Sorrell et al., 2004).

Municipalities in particular face difficulties in procuring, implementing and managing energy efficiency projects although these investments can alleviate financial constraints in the long run and help municipalities meet climate change targets (Bratt et al., 2013; Dena, 2015; Nolden et al., 2015; Radulovic et al., 2011; Schönberger, 2013; Singh et al., 2010; Testa et al., 2016). Procuring public sector energy efficiency retrofits and services through outsourcing (relational, long-term or performance-based energy contracts) may help overcome some of these barriers (Aasen et al., 2016). This process and various municipal governance options for procuring and retrofitting have received relatively little academic attention (Pätäri and Sinkkonen, 2014).

With energy efficiency gains of up to 90% compared to conventional lighting, LED streetlights provide a good example for the analysis of governance options of municipal energy efficiency procurement and retrofitting (Bennich et al., 2014; De Almeida et al., 2014). This paper analyses the role of different municipal governance arrangements for procuring, implementing and managing innovative energy demand reduction technologies (EUEDs) that reduce the absolute consumption of primary energy and the delivery of energy services using the example of Germany (Herring, 2006; Wilson et al., 2012). Germany is a particularly interesting research setting due to its diverse municipal energy service governance arrangements and corresponding procurement and retrofitting activities. This paper combines research on energy service markets (Bertoldi et al., 2014; Marino et al., 2011, 2010;

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Pätäri and Sinkkonen, 2014) with an analytical framework based on transaction cost economics (TCE) (Pint and Baldwin, 1997; Sorrell, 2007; Toffel, 2002).

The paper argues that, in the absence of appropriate municipal (in-house) governance structures capable of diffusing EUEDs, market-based solutions such as (performance-based or relational) energy service contracts can accelerate their commercialisation and diffusion. The transaction cost analysis reveals that municipal competencies represent a key factor for choosing an appropriate mode of governance for procuring and implementing EUED retrofits. Our research, which combines a longitudinal archival document analysis with 40 semi-structured interviews, addresses the following research question: *What is the appropriate mode of governance for procuring and retrofitting EUEDs and delivering associated energy services in municipalities?*

The remainder of this article is structured as follows: Section 2 reviews the relevant literature and introduces the theoretical framework. The research design including the qualitative research approach and the data is presented in Section 3. Section 4 displays the results which form the basis for discussion (Section 5) and conclusion (Section 6), including policy and management implications.

2. Literature review and analytical framework

2.1. Challenges facing adoption of novel end-use energy demand technologies

Compared to supply side low-carbon technologies, EUEDs have been marginalised, despite their diffusion considered essential to reach climate change targets while reducing costs and fossil-fuel dependency (Cagno and Trianni, 2014; IEA, 2014a, 2014b; Mickwitz et al., 2008; Sovacool, 2009). Wilson et al. (2012) attribute this to the nature of these technologies, such as their diversity and widespread application, small scale and low visibility. These factors hinder diffusion because they limit the individual rate of adoption (Rogers, 1995).

In general, barriers to diffusion arise from complex interdependent factors that relate to the nature of innovative technologies and environmental externalities (see Table 1). In this paper we differentiate between technological, institutional, economic and capacity factors. Technological factors comprise uncertainty about the dominant design, quality and increasing complexity of innovative technologies and application (Foxon and Pearson, 2008; Schleich, 2009; Sorrell et al., 2004; van Soest and Bulte, 2001). Institutional barriers include path-dependent technological application associated with investments into corresponding infrastructure, low acceptance among the local population or unanticipated or reoccurring changes in the policy design and slow administrative approval (Foxon and Pearson, 2008; Klein Woolthuis et al., 2005; Wilson et al., 2012). Volatile or artificially low energy prices and missing or incomplete carbon markets represent economic barriers to diffusion by increasing uncertainty (Gallagher et al., 2006; Jaffe et al., 2005; Sorrell et al., 2004). Investments in innovative EUEDs may be unprofitable as a result of long payback periods relating to high upfront costs and uncertainty about energy savings (Sorrell et al., 2004).

Finally, potential users require enhanced competencies and capacities to evaluate and implement innovative EUEDs (Klein Woolthuis et al., 2005; Schleich, 2009; Sorrell et al., 2004; Testa et al., 2016). As a result, customers often ‘wait’ for future improvements and fail to harness current savings. This is referred to as the ‘energy efficiency paradox’ (van Soest and Bulte, 2001). At the municipal level, the tendency to wait for future improvements and associated backlogs are particularly pronounced (Jensen et al., 2010). These factors represent key barriers for a range of EUEDs, including lighting, which this paper seeks to address (De Almeida et al., 2014; Fouquet and Pearson, 2006; Mills and Schleich, 2014).

2.2. Modes of governance for EUED procurement and retrofitting

In order to address the barriers to EUED diffusion, policy-makers are confronted with a number of measures to support the demand-side, such as regulation, public procurement, support of private demand (e.g. subsidies, tax incentives) and systemic policies (e.g. clusters) (Edler and Georghiou, 2007). Throughout this paper we focus in particular on public procurement alongside management and implementation as it has been identified as a crucial step for the diffusion of clean technologies such as EUEDs (Edler and Georghiou, 2007; Edquist and Zabala-Iturriagagoitia, 2012; Guerzoni and Raiteri, 2015; Testa et al., 2016). At the municipal level, policy-makers are presented with the choice of either sourcing innovative solutions directly *in-house*, procuring via *relational contracts*, via *long-term contracts* or via *performance contracts* (see Table 2, based on Williamson, 1985). The literature has highlighted the design of contractual arrangements (*mode of governance*) regarding contract duration and responsibilities as a critical factor for addressing risk and complexity especially during the procurement process (Hall et al., 2016; Hartmann et al., 2014; Pint and Baldwin, 1997; Roehrich and Lewis, 2014; Sorrell, 2005). Hartmann et al. (2014, p. 174) suggest that public sector organisations such as municipalities need to 'identify the procurement level and the contractual and relational challenges involved’ in a public-private partnership (PPP) to increase the economic viability and ensure the appropriate distribution of risks and benefits.

The *in-house* option maximises municipal control over procurement, as well as implementation and management, and appropriation of anticipated savings in energy and cost. However, this process is subject to a set of barriers perceived by suppliers of (green) innovative goods, such as the lack of interaction with procuring organisations, over-specified tenders, missing environmental criteria, low competencies of the procurers and poor

Table 1
Barriers to the diffusion of EUEDs.

Barriers to the diffusion (of EUED)	Examples	References
Technological	Standards, complexity, maturity, ‘reverse salients’ (i.e. unanticipated technological, environmental or social consequences), missing infrastructure	(Foxon and Pearson, 2008; Gee and McMeekin, 2011; Schleich, 2009; Sorrell et al., 2004)
Institutional/ political	Path-dependency, low acceptance, inadequate political environment, administrative procedures, information asymmetries	(Chadha, 2011; Foxon and Pearson, 2008; Henriot, 2013; Klein Woolthuis et al., 2005; Köhler et al., 2010; Wilson et al., 2012)
Economic/ financial	Investment risk, (small) scale, low energy prices, incomplete carbon markets (externalities), long payback periods, inappropriate business models	(Gallagher et al., 2006; Jaffe et al., 2005; Kenney and Hargadon, 2012; Kley et al., 2011; Sorrell et al., 2004; Hall et al., 2016)
Competency	Low visibility, other priorities, lack of time and capacities to evaluate EUED markets, lack of demand-articulating competencies	(Markard and Truffer, 2008; Schleich, 2009; Sorrell et al., 2004; Testa et al., 2016; Weber and Rohracher, 2012)

Table 2
Modes of governance for the procurement of EUEDs.

Mode of governance	Characteristics from a municipal perspective	References
In-house procurement	Complete control over the procurement and retrofitting process, the client bears all risks (related to barriers of diffusion)	(Testa et al., 2016; Uyarra et al., 2014)
MUCO (relational contracts)	Partial or complete ownership over the third party that carries out the retrofitting via a contract, risks partially transferred to third-party, no performance targets	(Bennett and Iossa, 2006; Betsill and Bulkeley, 2006; Hannon and Bolton, 2015; Hartmann et al., 2014; Roehrich et al., 2014)
EUCO (long-term contracts)	Partial ownership exceptional, contracts usually do not provide for contingencies or allow municipal interference, no performance targets	(Berlo and Wagner, 2013; Hannon et al., 2013)
ESCO (long-term performance contracts)	No ownership, details about risk-sharing and other responsibilities (i.e. performance targets) in the contract, guaranteed savings as a result of the retrofitting process	(Hannon and Bolton, 2015; Marino et al., 2011; Pätäri and Sinkkonen, 2014; Sorrell, 2007, 2005)

management of risk during the procurement process (Testa et al., 2016; Uyarra et al., 2014).

Relational contracts allow the public organisation to benefit from private sector organisational effectiveness and efficiency in providing services without losing strategic control. Depending on municipal risk-aversion, the extent to which the municipality wants to retain strategic control, the resources it has at its disposal and the surrounding regulatory framework, the municipality may choose (partial) ownership over the third party that carriers out retrofits and provides energy services (Hannon and Bolton, 2015). Relational contracting is of particular relevance in the German context as many municipalities have links to Municipal Utility Companies (MUCOs - known as Stadtwerke) (Bulkeley and Kern, 2006). MUCOs tend to provide a wide range of utilities such as gas, electricity and municipal waste management. Strong local embedding ensures that these MUCOs enjoy near monopolies on most supply and waste streams, which can provide incentives for integrated solutions (Betsill and Bulkeley, 2006).

The third alternative is a *long-term contract,* usually with an Energy Utility Company (EUCO), which typically engages in energy generation and supply at a national or international level. Long-term contracts with EUCOs are similar to relational contracts with MUCOs although municipalities are unlikely to have a stake in a EUCO. As a result, EUCOs are less likely to offer integrated solutions (Hannon et al., 2013). The incentive to 'wait' for future improvements rather than harnessing current savings is also greater for EUCOs than for MUCOs (Berlo and Wagner, 2013). Both relational and long-term contracts can be a solution in case public sector organisations, such as municipalities, run on very tight budgets (Bennett and Iossa, 2006; Hartmann et al., 2014; Roehrich et al., 2014).

The final option is outsourcing using *energy performance contracts (EPCs)*. EPCs are a sub-category of energy service contracts usually offered by Energy Service Companies (ESCOs) (Nolden et al., 2015; Sorrell, 2007). According to Sorrell (2007, pp. 507–508) ESCOs 'typically offer comprehensive contracts that include energy information and control systems, energy audits, installation, operation and maintenance of equipment, competitive finance, and fuel and electricity purchasing. These contracts transfer the decision rights over key items of energy equipment including incentives to maintain and improve equipment performance over time'. In this paper we refer to all companies offering innovative performance-based business models such as EPCs as ESCOs. EPCs can enable the cost-effective supply for a subset of energy services (Nolden et al., 2015; Sorrell, 2007). This is likely to be the case if they can offer specialised solutions. Independent ESCOs offering EPCs tend to benefit from the absence of long term contracts with manufacturers, which may lead to lock-in regarding the choice of technology, and they often incur lower costs for procuring equipment (Helle, 1997; Pätäri and Sinkkonen, 2014; Sorrell, 2007). In an EPC, the ESCO assumes control over secondary energy conversion and control equipment that converts primary energy streams into useful energy such as heating and lighting (Sorrell, 2007, 2005). This allows the ESCO to identify, deliver and maintain savings using guarantees for certain standards (e.g. lighting) at a cost typically lower than its customers' current or projected energy bill (Hannon et al., 2013; Marino et al., 2011; Sorrell, 2007).

2.3. Analytical framework: transaction cost economics

Transaction cost economics (TCE) represents a prominent theoretical perspective for analysing modes of governance and institutional structures between hierarchies and markets (Delmas, 1999; Selviaridis and Wynstra, 2015; Williamson, 1985). Transaction costs (TCs) depend on how the transaction is organised through governance structures and TCE makes 'several key assumptions about managerial behaviour when determining which governance structure is most efficient for a particular transaction' (Pint and Baldwin, 1997; Toffel, 2002, p. 2). TCs are incurred within organisations through managing and monitoring personnel, procuring inputs and capital investment, and 'the costs associated with organising ('governing') the provision of [...] streams and/or services' (Sorrell, 2007, p. 512). When the same streams and/or services are sourced from an external provider, transaction costs are associated with source selection, contract management and performance monitoring, dispute resolution and opportunistic behaviour (Pint and Baldwin, 1997; Sorrell, 2007). Transactions are governed through structures, which are located on a spectrum with hierarchical organisations (internal) at one end, spot markets (external) at the other, and hybrid mechanisms in between (Pint and Baldwin, 1997; Toffel, 2002). With increasingly complex customisation of services, more hierarchical governance structures may be appropriate to allow for adjustments to contingencies (such as the emergence of more efficient technologies) over the life of a contract (Pint and Baldwin, 1997). According to TCE, the choice between market-based, long-term contracts (outsourcing) and hierarchies (in-house provision) depends on the magnitude of associated transaction (TCs) and production costs (PCs).

The choice of governance structure also depends on characteristics of transactions as investment in transaction-specific (dedicated) assets may improve the efficiency of some transactions (Pint and Baldwin, 1997). A MUCO, EUCO or ESCO may already have acquired skills, equipment for both operation and maintenance (O&M) and measurement and verification (M&V) and established links with manufacturers. Acquired skills and the buyer-seller relationship can be classified as *human capital specificity* while specialised equipment falls under *technical asset specificity*. *Dedicated resources* is the degree to which organisations support a particular transaction (Pint and Baldwin, 1997; Toffel, 2002). The assumption is that transactions featuring *high technical asset specificity* and *dedicated resources* are less likely to operate efficiently within market transactions as the party that has not invested may threaten to cancel the contract to expropriate some of the invested value. Additional factors that influence the TCs of contracting are the *complexity of the task* (procuring and retrofitting technology and the complexity of monitoring performance according to contractual terms and conditions), the *competitiveness of the energy service market* and the *institutional context* in which contracting takes place (Sorrell, 2005). The institutional context can be affected by standardised tendering and procurement procedures and standardised measurement and verification (M&V). Clients such as municipalities are only likely to enter a long-term contract or performance contract if useful energy streams and final energy services can be supplied at a lower *total* cost compared to their provision using other modes of governance. Total costs are the sum of PCs, 'the expenditures for inputs such as fuel and electricity', which depend on technical and operational efficiency of the equipment, and TCs as outlined in this section (Sorrell, 2007, p. 512). Table 3 summarises the factors that determine the viability of an energy-service contract.

3. Methodology

3.1. Research design

To address our research question, we employed the TCE model (see Section 2.3) originally developed by Williamson (1985) and specified by Toffel (2002), Pint and Baldwin (1997) and Sorrell (2007). Sorrell's (2007) model in particular focuses on the economics of energy service contracts, which allows the analysis of modes of governance and their capacity to diffuse innovative EUEDs. We applied the framework to help understand which factors affecting TC represent drivers or barriers for the procurement of EUEDs among the modes of governance.

To develop an empirically-based perspective, a qualitative inductive methodology was applied (Eisenhardt, 1989; Yin, 2009). Within this frame, we chose analytic induction since we based our empirical work on an initial theoretical perspective also referred to as 'abduction' (Mantere, 2008; Patton, 2002). We conducted a case study to integrate different data sources and to holistically research a phenomenon within its real-life context, which is especially relevant when the limitations of the phenomenon are not clearly defined. Yet, the findings represent patterns rather than statistically validated results, which limits their generalizability. A case study can be defined as 'an intensive study of a single unit for the purpose of understanding a larger class of (similar) units' (Gerring, 2004, p. 342). When selecting a case, scholars need to ponder between the dimensions of representativeness and useful variation of the sample (Seawright and Gerring, 2008). Our analysis covers municipal street lighting as a case since it represents one of the most relevant and typical application for EUEDs and public procurement worldwide (De Almeida et al., 2014; McKinsey, 2012; Mills and Schleich, 2014; Radulovic et al., 2011).

3.2. Case study: LED street lighting governance in German municipalities

Lighting technology is currently going through a transition phase from traditional lighting technologies towards LED (De Almeida et al., 2014; McKinsey, 2012; ZVEI, 2015). Although LEDs are on the path towards technological maturity, industry-wide standards for fittings are still missing (for an extensive discussion of the evolution of lighting and services see Fouquet and Pearson, 2006). This transition fundamentally affects the business model of street lighting providers, such as municipalities, as original investments often date back 40–60 years. Major initial investments are necessary to retrofit existing street lighting stock and to tap into long-term energy efficiency benefits and savings associated with new technologies such as LEDs.

9.5 million public street lights installed in Germany consume approximately 4 TWh of electricity per year. Corresponding energy costs of about €750 m/a represent approximately one third of municipal energy costs. Municipal pricing models range from standard tariffs, to reduced tariffs for lighting to a pay-per-street-light, depending on the mode of governance. German municipalities are typically confined by budget restrictions as total municipal debt amounted to €133.6bn in 2013 (Difu, 2014; DStGB, 2014). The potential savings of switching to energy efficient lighting systems (especially LEDs) in Germany amount to €400 m/a (Dena, 2012; DStGB, 2010). Germany's market for public street lighting is highly dispersed, consisting of more than 11,000 municipalities with individual decision-makers.

Historically, different forms of municipal street lighting governance have emerged. In Germany 27% of municipalities provide street lighting in-house. 10% delegated (partially outsourced) the management to MUCOs. 35% outsourced lighting management to EUCOs. 25% partially outsourced services such as maintenance. 3% of German municipalities use ESCO solutions (Dena, 2012). Fig. 1 depicts our units of analysis, the main actors that take part in the procurement and retrofitting process. LED manufacturers produce the lamps which can be used either by municipalities directly if they own/operate the street lighting or by MUCOs, EUCOs or ESCOs if these entities assume control over the equipment. The retrofitting process is hampered by technological, institutional, competency and economic factors. Facilitators, such as energy agencies and consultants, can accompany the process by providing advice. Regulatory bodies oversee municipal finances and may (dis-) approve budgets, especially when a municipality is heavily indebted. Financiers mostly consist of (government-owned) banks, such as Germany's KfW bank, who finance municipalities as well as MUCOs, EUCOs and ESCOs. Germany has 4 EUCOs and around 900 MUCOs supplying energy (services) (Energy Transition, 2013). ESCO solutions are gaining acceptance among customers although the market has reached only 10% of its potential (Duscha et al., 2013). We identified 10 companies that offer ESCO lighting services to municipalities, which include subsidiaries of EUCOs or

Table 3
Modes of governance for the procurement of EUEDs.

Viability of modes of governance	TC-related factors	Examples	References
In-house, MUCO, EUCO or ESCO solutions	Technical asset specificity	Specialised equipment such as cranes, intelligent lighting etc.	(Pint and Baldwin, 1997; Sorrell, 2007; Toffel, 2002)
	Human capital specificity	Dedicated human resources for retrofitting	(Pint and Baldwin, 1997; Toffel, 2002)
	Dedicated resources	Specialisation in a particular area	(Pint and Baldwin, 1997; Toffel, 2002)
	Task complexity	Replacing old lighting technology with novel LED and monitoring performance	(Sorrell, 2007, 2005)
	Competitiveness of the market	Number of entries/exits in the energy service market	(Sorrell, 2007, 2005)
	Institutional framework	Regulation for energy efficiency or municipal budgets	(Sorrell, 2007, 2005)

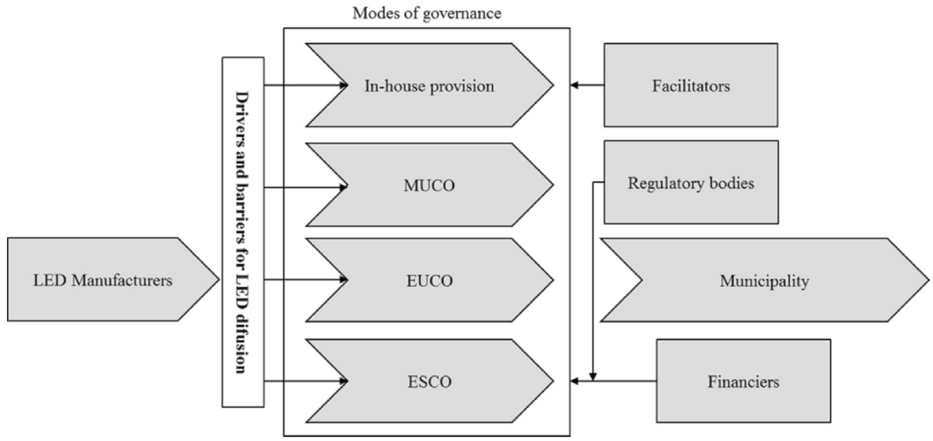

Fig. 1. Overview of actors and modes of lighting governance for LED diffusion.

infrastructure providers.

As established in Section 2.3, the choice of supplier represents a choice of governance structure. In-house provision represents a hierarchical governance structure. MUCO contracts can be considered relational contracts as they focus on the terms of the relationship. Shifting business models between privatisation (market) or 'recommunalisation' (hierarchy) may result in dynamic relationships between a municipality and its MUCO. EUCO contracts are likely to fall under the category of long-term contracts. ESCO solutions represent long-term performance contracts, the most market-based governance structure for street lighting (see Table 4).

It is assumed that the complexity of long-term (performance) contracts compared to relational contracts or conventional in-house procurement of equipment increases the TCs of negotiating and managing the relationship with the (energy) service provider or manufacturer (human capital specificity). Consequently, PCs resulting from the physical characteristics of the energy system and the technical efficiency of organisational arrangements need to be lower for associated modes of governance to be economically viable (Sorrell, 2007).

The case study of governance modes for public sector LED street lighting provides a good example as potential savings are high (LED modules are ten times more efficient than halogen for the same light output although the overall system efficiency is lower as losses occur due LED drivers and configuration of the lamp) and the capacity of municipalities to invest in these EUEDs is limited (Bennich et al., 2014; DStGB, 2014, 2010). Municipal benefits of abandoning the in-house approach in favour of more market based solutions may include reductions in energy costs, less exposure to energy price fluctuation and the transfer of risk, allowing the municipality to focus on core activities. More market-based modes of governance, however, imply a loss of municipal control and flexibility. There is a danger of third-party contractors cherry-picking the most profitable municipal tenders to the detriment of less attractive ones.

3.3. Data collection

Data was firstly collected through an extensive longitudinal archival document analysis (i.e. context of lighting and municipal public procurement from 2008 to 2013). This period covers the main commercialisation phase of LED lighting in Germany (De Almeida et al., 2014). Secondly, interviews allowed us to reflect upon changes in the industry and institutional context. The literature review covered industry reports for lighting and energy services and public procurement reports compiled by industry experts such as energy agencies, official government bodies or industry associations.

The main empirical focus of this paper is the analysis of 40 semi-structured interviews with key stakeholders. The interviews took place from October 2013 until January 2014. We selected interview partners according to an approach suggested by Seawright and Gerring (2008). Following an initial screening and a consultation of experts from Germany's 'LED Lead Market Initiative', we selected the most influential stakeholders in the process of LED application in German municipalities that directly engage in the process of street lighting modernisation (see Fig. 1) (BMBF, 2014).

For each of the modes of governance we compiled typical cases that are representative (Seawright and Gerring, 2008). Hence we combined snowball sampling and purposeful sampling strategies. An overview of our sample can be drawn from Table A.1. The interviews lasted 30–90 min and were conducted face-to-face or via telephone with one to two researchers present. The interviews were recorded (for later verification) and notes were taken (Patton, 2002). Representative quotes have been translated into English. Questions during the interviews revolved around two main topics, notably modernisation of public street lighting (participating actors, processes and facilitators) and the role of different modes of governance (see appendix for details). Supporting data cannot be made openly available due to ethical concerns (privacy of the respondents) but can be obtained by researchers upon request.

Table 4
Spectrum of governance structures for municipal street lighting in Germany (adapted from Pint and Baldwin (1997, p. 4)).

Hierarchies ···				···Markets
Vertical integration	Relational contracts	Long-term contracts	Long-term performance contracts	Simple short-term contracts
	Examples			
In-house lighting provision	MUCO contract for lighting provision	EUCO contract for lighting provision	ESCO solutions	Lighting arrangement for a recurring event

Further information about the data and conditions for access are available at the Sustainable Business Institute (SBI) Contact: www.sbi21.de.

3.4. Data analysis

We systematically evaluated the collected archival documents, analysed the interview protocols and reflected these against the bulk of documentations. We then analysed the material according to the research question concerning barriers to the uptake of innovative EUED technologies as well as the possible role of alternative modes of governance (Section 2.2) for accelerated uptake of public LED street lighting and addressing the corresponding challenges (see Section 2.1). In this process we identified the following main topics:

- Technological drivers and barriers
- Institutional drivers and barriers
- Economic and financial drivers and barriers
- Competency and capacities as both are required to examine and technological, institutional and economic/financial barriers and to enhance the diffusion of innovative EUEDs

These were reflected against concepts of TCE (technical asset specificity, human capital specificity, dedicated resources, task complexity and competitiveness of market) in an 'abductive' process, i.e. the back and forth between theory, interview transcripts and archival documents (Mantere, 2008). We then compared the modes of lighting governance, highlighting the suitability for each in different situations (financial situation, competency and capacity of actors, institutional set-up).

4. Findings: modes of German municipal street lighting governance and the diffusion of LEDs

This section provides an overview of factors affecting the uptake of EUEDs using the example of LEDs replacing conventional street lighting technology. For each section we firstly present the drivers and barriers that relate to technology, institutions, competence and economics/investment. Secondly, we analyse their effects on TCs and PCs depending on the different modes of governance (see Table 5 for an overview).

4.1. Technological factors

4.1.1. Technological complexity

LED lighting provides a technological advantage over conventional lighting: higher energy efficiency. Despite a high potential for energy (and PC) savings, the first set of barriers to LED diffusion comprises technological aspects such as the maturity of the products, complexity and uncertainty regarding energy savings and durability. This was highlighted by LED customers such as ESCOs and municipalities. Also the manufacturers admit, '*there is tremendous uncertainty regarding new measures to evaluate the performance of LEDs, for example maintenance factors and payback periods' (Manufacturer).* The TC analysis reveals that technical change and the lack of standardisation leads to increased technical asset specificity and task complexity for the municipality.

4.1.2. Standardisation and warranties

Some LED customers (i.e. MUCOs, EUCOs and municipalities) further highlighted missing standardisation and short warranties of LED due to the early stage in the innovation cycle, as well as technological path-dependency relating to less innovative and less efficient lighting systems currently being installed, as barriers to LED uptake. '*Many sales people from LED manufacturers have been to our town. There are too many standards and warranty mechanisms' (Municipal representative).* ESCOs on the other hand embrace the novelty of the technology and base their business model upon energy savings. In TC terms, barriers associated with the technical asset specificity of LED lighting and the task complexity of both assessing technology offers up-front and M&V for potential savings translate into higher TCs in the absence of appropriate skills and capacities. This is more likely to be the case for in-house procurement than for market-based solutions.

4.2. Competency and capacity factors

4.2.1. Municipal competencies

Despite the provision of advice by the German federal government and numerous other players such as the German Energy Agency and the 'LED lead market initiative', all stakeholder groups agreed that missing competency represents a common barrier among the 11,000 municipalities (BMBF, 2014; SBI, 2013). Competency barriers relate to the capacity of actors to overcome technological, market and institutional barriers.

On one hand, municipal representatives often fail to evaluate the market for LED lighting concerning quality, energy savings and risks. '*The implementation of the modernisation is demanding. You need to know the technical details and test examples in practice (Municipal representative)'.* On the other hand, municipal representatives often lack the administrative competency to design tenders with appropriate quality and endurance criteria and to carry out comprehensive budgeting and cost management throughout the procurement process of LED street lighting, which was highlighted by potential third-party contractors. '*Usually [municipal representatives] don't know about their own costs for lighting. Data about the old lighting systems in terms of energy costs, investments etc. is missing (Manufacturer)'.* These competencies were not necessary in the past, as more efficient technologies evolved slowly.

In the case of low human capital specificity dedicated towards municipal energy management, outsourcing may be a sensible option but the difficulty of designing tenders may prove too complex a task for a municipality to consider. This translates into high TCs. Our results show that the responsible decision-makers tend to ignore or reject market-based solutions as the perceived human capital specificity for appropriate tender design is too high.

4.2.2. Open-book accounting and cost-transparency

According to third-party contractors (i.e. MUCOs, EUCOs and ESCO s alike), a push for open-book accounting was a robust success factor since anticipated cost-savings are one of the main drivers for municipalities to modernise their lighting infrastructure. '*I think one of the main barriers is the municipal accounting system. Usually the overall costs for running their lighting system are higher than what we estimate during the planning process (ESCO)'.* Municipalities also highlight cost transparency and cost management systems as facilitators of outsourcing solutions for retrofits as the procuring agency can compare baseline and future scenarios. '*The main preconditions for effectively modernising the lighting systems lie in a lighting database and a clear guideline. So you turn that into a functional, neutral tender (Municipal representative)'.* However, a lot of municipalities still lack these systems and procedures. The interviewees agreed upon the need for early decision-makers involvements from local government and administration to further facilitate their use. Neutral tenders ensure technology-neutral bidding and realisation although manufacturers fear losing their long-term partnership with municipalities as a result.

Open-book accounting and cost-transparency lowers TCs for more market-based solutions as the availability of consumption figures enables more precise calculations of potential savings and adequate tenders to be set up. These factors reduce human capital specificity and task complexity for outsourcing as they reduce the need for information acquisition.

4.2.3. Facilitators

Municipalities and ESCOs highlighted the positive role of facilitators (e.g. energy agencies) and other consultants as well as best practice examples during the tender and implementation process for the assessment of governance modes. They provide the necessary lighting and planning expertise. If, on the other hand, intermediaries and facilitators suffer from a lack of lighting competence, a bias towards established technologies emerges. Failing to understand the complexity of tendering processes may also increase the complexity of determining savings. '*The building and energy context requires a lot of expertise. Energy consultants are lacking the competence for functional lighting tendering. So manufacturers and their tools to calculate savings dominate the market (Energy consultant)*'. EUCOs and MUCOs should fulfil this role. However, they are usually reluctant to deploy more innovative technologies.

In the TC analysis, facilitators in particular hold a critical position as they may lower the TC for more market-based governance structures and offset the need for in-house capacities to procure, implement and manage retrofits. Search costs and dedicated human capital specificity may be reduced by providing a concrete overview of available options. However, low human capital specificity and dedicated resources of facilitators may increase TCs for more market-based solutions.

4.3. Institutional factors

4.3.1. Property situation and established partnerships

Institutional barriers on the demand side relate to the property situation (many German municipalities sold their street lighting to EUCOs) and specific structural arrangements for the provision of public street lighting which in Germany has historically often been a task for MUCOs, as municipalities and ESCOs pointed out. MUCOs and EUCOs consider themselves capable of dealing with technological change. However, '*existing contracts with EUCOs often run for a very long time and the EUCO only complies with the legal minimum when it comes to efficiency. A switch to LEDs, which would make sense, does not happen. They use less efficient technologies (ESCO)*'. ESCOs highlighted their technological and tendering competencies, which are often hindered by the property situation relating to long-term relational contracts that do not provide the right incentives to encourage the diffusion of innovative technologies such as LED.

Additionally, manufacturers often dictate the tenders as a result of long lasting partnerships, a point which was observed by their clients. This setup implies that they can charge individual prices for each customer including ESCOs, MUCOs or EUCOs. '*The manufacturers are the winners in this market. They often have long lasting partnerships with the municipalities, they supply analyses for free. Many tenders thus specify one product (ESCO)*'. Contractual barriers also relate to lighting arrangements with EUCOs. In many cases they prevent market-based solutions, particularly EPCs, to be considered. Our TC analysis reveals that time consuming and costly switching procedures from one contractor to another translate into human capital specificity and increase TCs for more market-based solutions.

4.3.2. Engaging in more market-based solutions

When municipalities are willing to engage in more market-based solutions such as performance contracts, experiences tend to be positive. '*The risks taken by the ESCO exceed the amount of financial savings I have when I do the modernisation by myself (Municipal representative)*'. TC analysis reveals that high human capital specificity required for lowering the risk of in-house EUED retrofits may lend itself to more market-based governance structures such as ESCO solutions, which have the potential to lower TC and total cost.

However, efforts required to govern the relationship with an external supplier are associated with task complexity and human capital specificity required for negotiating and monitoring contracts. This fact was stressed by third-party contractors and independent actors such as energy agencies and financiers alike. '*There is a complexity problem. Many contract documents exceed 50 pages (Financial service provider)*'. Regarding performance contract design municipal representatives as well as ESCOs underline transparency, comprehensibility and a distinct guarantee for energy savings as beneficial. '*Guidelines, transparency of the contract and an ESCO that selects high quality products turned out to be successful (Municipal representative)*'. Regarding the performance contract design, municipal actors in particular also emphasised the need for flexibility (e.g. to allow for contingencies) and a fair balance of interests during the contract negotiations. '*We need flexibility regarding short- medium- and long-term developments in the markets (Municipal representative)*'. An exact definition of the baseline, however, often proves difficult, especially in smaller municipalities. '*Complexity of [performance] contracting leads to high TCs. Exact numbers are needed (Energy agency)*'. The TC analysis indicates that increasing experience and enabling structures for retrofitting significantly reduce task complexity of performance contracts, particularly if contractual arrangements align interests by providing transparency and flexibility.

According to ESCOs, performance contracts also need to be checked by regulatory bodies when municipalities run on a very tight budget in need of consolidation. '*The regulating authorities need to approve the [performance] contract. The financing over the contract duration needs to be assured (Municipal agency)*'. In this regard, our TC analysis points towards administrative approval as a dedicated institutional resource to counterbalance missing dedicated municipal resources.

In addition, few organisations target the lighting market with performance contracts as independent actors observe. '*Street lighting does not receive the attention it deserves in terms of potential cost savings and improvements in lighting quality (Energy agency)*'. Manufacturers, who could also offer performance contracts, generally show little willingness to enter the service based market segment as they perceive the margins as low and complexity as high. In TC terms, specialised ESCOs gain a competitive advantage in the field of lighting. Low competitiveness in the ESCO market, on the other hand, increases TCs as it reduces the likelihood of municipalities to consider outsourcing through performance contracts and discourages ESCOs to provide cost effective solutions.

4.4. Economic/investment factors

4.4.1. Economic (dis)incentives for retrofitting

Economic barriers stem from relatively high upfront costs of LED street lighting. This is of particular relevance for municipalities (but also for other LED customers) as they typically run on a tight budget, in some cases tightly controlled by regulatory bodies with budgetary control powers (see Fig. 1) as highlighted by municipalities and facilitators. Volatile energy prices (with a slight upward trend for end-users) and uncertain price developments for LEDs increase the complexity of calculating the payback of investments, as municipalities point out. EUCOs and MUCOs often are less dependent on market prices and consequently do not consider this problematic. In TC terms, these factors prevent municipalities from evaluating significant PC savings, which is a prerequisite for considering any alternative mode of governance for modernisation, by increasing human capital specificity and task complexity.

4.4.2. Selling services vs. selling primary energy

EUCOs and MUCOs can realise financial savings by lowering the cost for supplying energy and better procurement conditions thanks to long lasting contracts with manufacturers. In addition, they may be both familiar with the current lighting system and experienced in providing maintenance services for municipalities. Hence both EUCO and MUCO solutions may (self-reportedly) exhibit higher savings for the provision of the final energy services. However, these companies may be subject to a conflict of interests, as they engage in selling electricity as opposed to providing energy efficiency services, which was pointed out by ESCOs and independent actors such as energy consultants. These actors exhibit conservative attitudes towards innovative technologies which may also prevent them from deploying LEDs. ESCOs, on the other hand, possess better procurement conditions for lighting equipment, which potentially favours a performance contracting solution for innovative EUEDs such as LED. TC analysis reveals potential for lowering TC among market-based governance modes in case the competitiveness of the energy service market is increased.

4.4.3. Financing costs

Municipal governance modes for retrofitting also differ with regard to their financing costs. Municipalities and (publicly owned) MUCO solutions benefit from low interest rates as public actors enjoy high creditworthiness. '*ESCOs [on the other hand] need to refinance themselves. However, forfeiting is not accepted by many municipalities. This leads to financial constraints for ESCOs (Financial service provider)*'. TC analysis reveals that ESCO solutions might exhibit higher financing costs, which reduces their potential to cut PC.

5. Discussion

5.1. Barriers to LED diffusion and outsourcing

Our findings provide an overview of technological, institutional, competency and economic barriers to the diffusion of novel EUEDs, especially in the procurement process (Bratt et al., 2013; Testa et al., 2016). First, LED customers and manufacturers alike have a similar perception of risks associated with technological uncertainty and missing warranties (Foxon and Pearson, 2008; Schleich, 2009; Sorrell et al., 2004). Depending on the business model of the clients (i.e. municipalities, MUCOs EUCOs or ESCOs), however, novelty may be embraced to harness and maximise savings. Second, institutional barriers such as administrative procedures, information asymmetries, path-dependency and property situations specifically relate to incumbent actors such as EUCOs and MUCOs (Chadha, 2011; Klein Woolthuis et al., 2005; Wilson et al., 2012). This prevents new energy service solutions to enter the market which would increase competition and hence efficiency in the long run. This is aggravated by an inadequate political environment. Third, we confirm competency barriers to EUED diffusion such as low visibility, other priorities, lack of time and capacities to evaluate EUED markets on the client side (Gallagher et al., 2006; Kley et al., 2011; Sorrell et al., 2004). However, these barriers could be reduced by increasing transparency (for M&V) and encouraging open-book accounting, which also benefit market-based solutions. Fourth, economic barriers such as (small) scale, low or volatile energy prices and long payback periods severely impact the viability of

Table 5
TCE perspective - Factors affecting the governance of novel EUEDs.

Factors affecting uptake of LED and choice of governance mode		Transaction costs (TC)	TCs for governance mode	
			Lowering TCs	Increasing TCs
Technological factors	Measurement and verification of savings	Technical asset specificity and task complexity	For MUCO, EUCO solutions	For ESCO solution
	Lack of standardisation	Technical asset specificity and task complexity	For MUCO, EUCO, ESCO solutions	For in-house
	Short warranties	Technical asset specificity and task complexity	For MUCO, EUCO, ESCO solutions	For in-house
Competency and capacity factors	Cost transparency and neutral tenders	Human capital specificity and task complexity	For ESCO, MUCO, EUCO solution	For in-house
	Open-book accounting	Human capital specificity	For ESCO, MUCO, EUCO solution	For in-house
	Expert facilitators	Human capital specificity	For ESCO, MUCO, EUCO solution	For in-house
Institutional factors	Lock-in contracts with existing suppliers	Human capital specificity	In-house, MUCO or EUCO solution	For ESCO solution
	Risk transferral	Human capital specificity	For ESCO solution, EUCO solution	For in-house, MUCO solution
	Transparency and flexibility of outsourcing procedure and contracts	Human capital specificity and task complexity	For ESCO solution	For in-house, MUCO and EUCO solution
	Administrative approval procedure	Dedicated resources	For in-house solution, MUCO, EUCO	For ESCO solution
	Low energy service market competitiveness	Competitiveness of the market	In-house, MUCO or EUCO solution	For ESCO solution
Economic/investment factors	Volatile energy prices and uncertain technological development trajectories	Human capital specificity and task complexity	For ESCO solution	For in-house, MUCO, EUCO solution
	Experience of current lighting system and providing maintenance	Dedicated resources	For EUCO or MUCO solution	For in-house, ESCO solution
	EUCOs and MUCOs potentially selling and saving energy	Competitiveness of the market	ESCO solution	For in-house, EUCO, MUCO solution
	Financing environment	Competitiveness of the market	For in-house, EUCO, MUCO solution	For ESCO solution

novel EUEDs (Gallagher et al., 2006; Kenney and Hargadon, 2012; Sorrell et al., 2004). Market-based business models could partly offset these barriers through performance contracts and risk transfer from the municipality to the third-party contractor.

5.2. Modes of governance for procuring and retrofitting end-use energy demand technologies

Based on the TC analysis of factors relating to the diffusion of EUEDs, we developed a taxonomy relating to the optimal mode of governance in different procurement set-ups (see Table 6). First of all, municipalities could manage EUED procurement, implementation and management in-house. To achieve economically viable solutions, significant technical and commercial know-how to evaluate technologies, markets and the institutional background is required. This translates into high TCs for retrofitting as human capital and technical asset specificity associated with potentially risky investments in innovative technology are high. There is also a danger of lower PC savings by inadvertently deploying inefficient products. However, if sufficient capacities are available and risk can be adequately mitigated against, in-house solutions provide the greatest opportunities for cost savings by maximising municipal control (Hannon and Bolton, 2015). If technological barriers can be overcome, the municipality features high competency and capacity, institutional factors remain intransparent and the economic situation stabilises, in-house approaches for retrofitting feature lowest TC (see Table 6).

Second, municipalities may be able to choose relational contracts with MUCOs for retrofitting EUEDs (which is of particular relevance in Germany given their presence in many municipalities). As these trusted relationships feature interwoven knowledge of existing technologies and infrastructure, the task complexity for contract management and the human and technical asset specificity of MUCO solutions for EUED retrofitting and diffusion are likely to be low (see Table 5) (Backlund and Eidenskog, 2013; Bulkeley and Kern, 2006). Relational contracts with a MUCO could therefore have an advantage over an in-house, long-term EUCO or ESCO solution. On the other hand, these companies usually supply energy to the municipality as well, which may reduce their incentive to apply innovative EUED technologies. We hereby extend the discussion surrounding energy services and the resulting design of public-private partnerships in the utilities sector and possible forms of ownership or control (Hannon and Bolton, 2015; Hartmann et al., 2014; Roehrich et al., 2014). A MUCO solution features lowest TC in case of high technological uncertainty, low municipal capacities, an unfavourable institutional environment and a favourable economic environment (see Table 6).

Third, long-term contracts with a EUCO provide the benefit of large, often systemic companies rolling out technologies on a large scale and providing municipalities with simple municipal buy-in options. The downside is that there is little incentive for EUCOs to push for the diffusion of innovative technologies, especially in the absence of performance related contractual elements. We thereby present technology specific results to the discussion surrounding EUCOs role in the low-carbon transition (Hannon et al., 2013). Long-term contracts exhibit the lowest TC if a standardised, proven technology is being used and low municipal capacities prevail. This mode of governance also requires favourable institutional and economic environments (see Table 6).

Fourth, performance contracts with ESCOs may achieve cost savings from the beginning of the contract and additional cost savings due to freed personnel capacity. However, the transfer of risks and uncertainty regarding technological components and development from the municipality towards the ESCO goes hand in hand with a loss of municipal decision-making rights. On the other hand, ESCOs may combine EUED retrofitting with energy or facilities management services using innovative business models (Bertoldi et al., 2014; Hannon et al., 2013; Pätäri and Sinkkonen, 2014). From a TC perspective, an ESCO solution is most viable for innovative technologies, low municipal competencies and an unfavourable economic environment. To achieve its potential, however, a favourable institutional environment is required (see Table 6).

With our analysis we extend the view of previous studies that performance contracts can lead to lower costs for the provision of energy services (Hall et al., 2016; Pätäri and Sinkkonen, 2014). In case customers demand high flexibility during the contract duration as they fear being locked into unknown new technologies, our results confirm previous findings which suggest an emphasis on the establishment of trusting relationships, particularly during the set-up of the contract (Backlund and Eidenskog, 2013; Roehrich and Lewis, 2014). To fully exploit the potential of market-based solutions in the municipal context, we can confirm the need for tenders not to over-specify to allow technology neutral bidding (Testa et al., 2016; Uyarra et al., 2014).

5.3. Using TCE for the analysis of governance modes for municipal energy service provision

We contribute to the literature on energy service markets (Marino et al., 2011; Nolden and Sorrell, 2016; Pätäri and Sinkkonen, 2014; Sorrell, 2007) a qualitative TCE framework that can be used to analyse different modes of governance for public-private interaction. LEDs provide a particularly good case study for applying TCE due to the nature of the underlying technology (its 'isolation', economies of scale and large energy savings). Public sector LED street lighting is also likely to fulfil several preconditions hypothesized by Sorrell (2007) for outsourcing using performance contracts, such as low technical asset specificity and low human capital specificity. However, our assessment of technological, institutional and economic barriers points towards enhanced competencies on the municipal side as a prerequisite for

Table 6
Taxonomy of governance modes.

Factors affecting the uptake of EUEDs (LED)	Characteristics of the factors	Mode of governance with lowest TC
Technological factors	High (new complex technology, uncertainty) Low (standardised, proven technology)	MUCO, ESCO solution In-house solution, EUCO solution
Competency and capacity factors	High (in-house capacities and/or facilitator) Low (no capacities, facilitators)	In-house solution ESCO, EUCO, MUCO solution
Institutional factors	Favourable (energy service market, risk is transparent, budgetary control) Unfavourable (lack of transparency, opaque administrative rules)	EUCO, ESCO solution In-house, MUCO solution
Economic/investment factors	Favourable (predictable energy prices, low financing costs, reliable partners) Unfavourable (volatile energy prices, adverse incentives, high financing costs)	In-house, MUCO or EUCO solution ESCO solution

considering market-based governance structures that may accelerate the diffusion of innovative EUEDs (see Table 5).

Analysing the diffusion of other EUEDs is nevertheless likely to be more complicated given the particular characteristics of lighting, specifically street lighting. Despite these limitations, our approach provides insights into drivers and barriers that constitute technological, economic, institutional or competency factors and how these in turn relate to higher or lower TCs of EUED procurement and retrofitting. Many of our case study participants considered the energy service fee for ESCO solutions comparatively low compared to the risk and complexity associated with in-house procurement and retrofitting of new energy related products (such as LED) and services. This is particularly relevant for street lighting as many municipalities rarely engage in the procurement of retrofits and hardly any have experience with LEDs. In the absence of MUCOs and trusted EUCOs (and when the municipality features low in-house competency and a tight budget), our TCE analysis reveals that ESCOs can reduce human capital specificity for retrofitting and contribute to reducing opportunistic behaviour towards the municipality, especially if ESCOs act as facilitators between EUED providers and municipalities. With an ESCO solution, municipalities might be able to source comprehensive knowledge from the market. Table 5 suggests that standard procurement rules, model contracts as well as facilitators could help lower TCs for market-based and especially ESCO solutions, which coincides with earlier findings by Bleyl et al. (2013), Roehrich and Lewis (2014) and Nolden et al. (2015).

Our major contribution to the advancement of TCE is its suitability for the analysis of different modes of governance for EUED procurement and retrofitting (Pint and Baldwin, 1997; Sorrell, 2007; Toffel, 2002). Factors influencing the diffusion of EUEDs in general (technology, competency, institutional and economic) have been related to factors influencing the TCs of different governance modes (technical asset and human capital specificity, dedicated resources, task complexity, competitiveness), to compare the viability of various modes of governance. Based on our results we argue to include the notion of competencies and capacities (quality and quantity), which tend to be 'hidden' behind 'dedicated resources' and 'human capital specificity' in TCE frameworks (Pint and Baldwin, 1997; Sorrell, 2007; Toffel, 2002).

6. Conclusions and implications

6.1. Conclusions

Our findings show that the municipal choice of governance options for procuring and retrofitting EUEDs depends on technological, institutional, competency and economic factors (see Table 6). In the absence of sufficient in-house capacities, relational contracting options (MUCOs), trusted partnerships for conventional long-term contracts (EUCOs) or emergent performance based ESCO solutions represent a vehicle for the commercialisation and diffusion of EUEDs.

The design and content of tenders emerged as a key phase during the adoption of EUEDs and the assessment of governance options. To address competency and capacity barriers, criteria to design these tenders should be widely diffused to increase transparency and competition among organisational (governance) structures, including documentation and guidelines or instruments to calculate baseline and savings (e.g. with standard tendering processes). Also, there is the need for flexibility when negotiating contracts with third parties. Intermediaries (e.g. consultants or energy agencies) emerged as key drivers for retrofitting and the diffusion of EUEDs in general and more market-based modes of governance in particular as they may address competency and capacity gaps, which represent the main barrier.

High associated TCs might hinder competition among more market based solutions and consequently decrease competition in the energy service market. Our results emphasise the discrepancy between the theoretical fit of market-based solutions, particularly given unfavourable economic conditions highlighted in Table 6, and actual diffusion. Only 3% of German municipalities use ESCO solutions. In other European countries EPC also represents a niche application (Combines, 2014; Transparense, 2013), which points towards the existence of strong interdependencies between actors and a conservative institutional environment. This 'lock-in' may be a reason for the slow diffusion of LED lighting as a case in point, EUEDs in general and/or ESCO solutions which could increase competition in the energy service market. The presence of a MUCO provides a particularly strong case for maintaining such a set-up as it provides opportunities to strengthen local capacity to manage energy and retain benefits from the diffusion of innovative EUEDs, which could be an incentive for municipalities in other countries to establish MUCOs by learning from the German case. Experience with EPCs for street lighting, on the other hand, is likely to reduce the TCs for the diffusion of other EUEDs using performance contracts.

6.2. Implications for policy makers and managers

As performance contracts prove very useful to accelerate the diffusion of LED street lighting and associated services in resource and capacity constrained municipalities, providing tender guidelines and resources for intermediary organisations can accelerate the diffusion of performance contracting, which in turn encourages the diffusion of LEDs. Experience with EPCs for street lighting is also likely to reduce the TCs for the diffusion of other EUEDs using performance contracts.

Currently, in this specific early phase of commercialisation of LED, there are no standards established and the typically guaranteed life time of the components and LEDs (to harness energy savings) is shorter than the pay-back period of the investment. Hence technological standards or enhanced warranties to address technological complexity as well as standard contracts to address legal complexity are required. Also, introducing statutory obligations for tendering to include more market-based solutions can improve the choice and competition among governance modes, which may foster competition in the energy service market. These could be established at a national level to actively support the diffusion of EUEDs at the local level. Additionally, policy-makers need to address institutional barriers by providing the infrastructure necessary to facilitate the implementation of innovative EUEDs, for example by rethinking long-term partnerships with MUCOs, EUCOs or other partners such as lighting manufacturers at the municipal level. Depending on the institutional set-up, establishing a performance contract with a MUCO could also be a way to lower the costs and risk associated with modernisation.

As highlighted above, to further foster the choice between hierarchical and market-based solutions, policymakers need to support facilitators (e.g. consultants or energy agencies) to disseminate specific technological and commercial knowledge (Bleyl et al., 2013; see also Lemon et al., 2015; Nolden and Sorrell, 2016). Corresponding regulations could be introduced at the national or state level. Although not specifically the focus of this research, market-based solutions for lighting such as performance contracts often face a lack of finance, which represents a significant economic barrier. Government owned banks (such as Germany's KfW), or governments themselves, could provide credit guarantees to improve access to finance to increase the competitiveness of the LED street lighting market and the wider EUED market as a policy response at the national level.

From a managerial perspective, we specifically highlight implications for ESCO market players, as these are new to the lighting market. ESCOs targeting the public market for energy efficiency should focus on a combination of products and services that fits the underlying prolonged technological lifecycle. Providing municipalities with a range of complementary services may increase their customer loyalty and reduce energy consumption and related costs in the long run. ESCOs need to follow an open-book approach in order to attract attention from municipal clients demanding high transparency, flexibility and a balance of interests. The use of standard contracts may fulfil these requirements (BMBF, 2014; SBI, 2013).

6.3. Limitations and future research

Our use of TCE in exploratory qualitative research, as opposed to rigorous model testing, exhibits limitations regarding the measurability of the constructs. Conclusions derived from this study are based on the recognition of patterns and do not represent generalizable results. However, due to the breadth of governance modes analysed, the findings are transferable to other contexts.

Our conclusions derived from this study form the basis for a quantitative survey (i.e. a survey of local authorities). Further analysis of markets and technologies could be valuable to explore the viability of more market-based governance structures in different institutional contexts. Finally, the conditions for market-based solutions to maintain a competitive position provide an interesting field for future research (Hannon et al., 2013; Hannon and Bolton, 2015). In relation to that, scholars could further explore why the creation of a market for performance contracts in a public context did not achieve its potential so far (Pätäri and Sinkkonen, 2014).

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Appendix

7.1. Interview guide

Modernisation of (retrofitting) public street lighting (by using LED).

- How does the process of modernisation (retrofitting process) unfold in the municipalities?
- Which technologies have been applied in the modernisation process (retrofit)?
- What role did the participating actors (EUCOs, MUCOs ESCOs, manufacturers and financial service providers) play?
- What factors influence their decision making?
- How does the regulatory or political environment influence the modernisation process?

Role of energy service contracts (EPC).

- What are perceived specific success factors and barriers of EPC for LED street lighting in a municipal context?
- How is technological and financial risk treated in these arrangements?
- Can EPC accelerate the diffusion of eco-innovations?

7.2. Interview participants

Table A.1
Sample.

Nr	Category	Position	Format	Date	Interviewer
1	Municipal representatives	Lighting engineer	Via telephone	Oct 2013	FP, PvF
2	Municipal representatives	Member of parliament	Via telephone	Oct 2013	FP
3	Municipal representatives	Technical manager	Via telephone	Oct 2013	FP
4	Municipal representatives	Energy efficiency manager	In person	Jan 2014	FP
5	Municipal representatives	Building authority	Via telephone	Oct 2013	FP
6	Municipal representatives	Building authority	Via telephone	Nov 2013	FP
7	Municipal representatives	Lighting manager	In person	Nov 2013	FP
8	Municipal representatives	Building authority	Via telephone	Nov 2013	FP
9	Municipal representatives	Lighting manager	Via telephone	Nov 2013	FP
10	Municipal representatives	Lighting manager	Via telephone	Nov 2013	FP
11	Municipal representatives	Lighting manager	In person	Jan 2014	FP
12	LED Manufacturers	Engineer	Via telephone	Oct 2013	FP, PvF
13	LED Manufacturers	Business developer	In person	Nov 2013	FP
14	LED Manufacturers	Business developer	Via telephone	Dec 2013	FP
15	LED Manufacturers	CEO	In person	Jan 2014	FP
16	LED Manufacturers	Chief marketing officer	In person	Nov 2013	FP
17	Energy service companies ESCOs	Business developer lighting	Via telephone	Oct 2013	FP
18	Energy service companies ESCOs	Business developer lighting	Via telephone	Oc 2013	FP
19	Energy service companies ESCOs	CEO	Via telephone	Nov 2013	PvF
20	Energy service companies ESCOs	Business developer lighting	Via telephone	Nov 2013	FP
21	Energy service companies ESCOs	Chief marketing officer	Via telephone	Oct 2013	FP

(*continued on next page*)

Table A.1 (*continued*)

Nr	Category	Position	Format	Date	Interviewer
22	Municipal-utility companies MUCOs	CEO	Via telephone	Oct 2013	PvF
23	Municipal-utility companies MUCOs	Lighting manager	Via telephone	Nov 2013	FP
24	Municipal-utility companies MUCOs	Lighting manager	Via telephone	Dec 2013	FP
25	Municipal-utility companies MUCOs	CEO	Via telephone	Dec 2013	FP
26	Municipal-utility companies MUCOs	Lighting manager	In person	Jan 2014	FP
27	Financial service providers	Key account manager for municipal clients	Via telephone	Nov 2013	PvF
28	Financial service providers	Expert on financing energy efficiency projects	Via telephone	Jan 2014	FP, PvF
29	Financial service providers	Key account manager for municipal clients	Via telephone	Jan 2014	FP, PvF
30	Regulatory bodies	Municipal budgetary expert	Via telephone	Jul 2013	FP
31	Regulatory bodies	Municipal budgetary expert	Via telephone	Jul 2013	FP
32	Regulatory bodies	Municipal budgetary expert	Via telephone	Jul 2013	FP
33	Regulatory bodies	Municipal budgetary expert	Via telephone	Oct 2013	FP
34	Facilitators	Energy agency	Via telephone	Oct 2013	FP
35	Facilitators	Energy agency	Via telephone	Oct 2013	FP
36	Facilitators	Public property manager	In person	Dec 2013	PvF
37	Facilitators	Energy consultant	In person	Nov 2013	FP
38	Facilitators	Energy consultant	Via telephone	Dec 2013	FP
39	Facilitators	Municipal agency	Via telephone	Dec 2013	FP
40	Facilitators	Energy agency	Via telephone	Nov 2013	FP

Notes: Friedemann Polzin (FP), Paschen von Flotow (PvF).

References

Aasen, M., Westskog, H., Korneliussen, K., 2016. Energy performance contracts in the municipal sector in Norway: overcoming barriers to energy savings? Energy Effic. 9, 171–185. http://dx.doi.org/10.1007/s12053-015-9356-0.

Backlund, S., Eidenskog, M., 2013. Energy service collaborations—it is a question of trust. Energy Effic. 6, 511–521. http://dx.doi.org/10.1007/s12053-012-9189-z.

Bennett, J., Iossa, E., 2006. Delegation of contracting in the private provision of public services. Rev. Ind. Organ 29, 75–92. http://dx.doi.org/10.1007/s11151-006-9110-z.

Bennich, P., Schoenen, B., Scholand, M., Borg, N., 2014. Test Report – Clear, Non-directional LED Lamps.

Berlo, K., Wagner, O., 2013. Stadtwerke-Neugründungen und Rekommunalisierungen: Energieversorgung in kommunaler Verantwortung; Bewertung der 10 wichtigsten Ziele und deren Erreichbarkeit; Sondierungsstudie.

Bertoldi, P., Boza-Kiss, B., Panel, S., Labanca, N., 2014. ESCO Market Report 2013, JRC Science and Policy Reports (Ispra, Italy).

Betsill, M.M., Bulkeley, H., 2006. Cities and the multilevel governance of global climate change. Glob. Gov. A Rev. Multilater. Int. Organ. 12, 141–159. http://dx.doi.org/10.5555/ggov.2006.12.2.141.

Bleyl, J.W., Adilipour, N., Bareit, M., Kempen, G., Cho, S.-H., Vanstraelen, L., Knowledgecenter, F., 2013. ESCo Market Development: a Role for Facilitators to Play.

BMBF, 2014. LED Leitmarktinitiative [WWW Document]. URL. http://www.photonikforschung.de/forschungsfelder/beleuchtungled/led-leitmarktinitiative/ (accessed 11.5.14.).

Bratt, C., Hallstedt, S., Robèrt, K.-H., Broman, G., Oldmark, J., 2013. Assessment of criteria development for public procurement from a strategic sustainability perspective. J. Clean. Prod. 52, 309–316. http://dx.doi.org/10.1016/j.jclepro.2013.02.007.

Bulkeley, H., Kern, K., 2006. Local government and the governing of climate change in Germany and the UK. Urban Stud. 43, 2237–2259. http://dx.doi.org/10.1080/00420980600936491.

Cagno, E., Trianni, A., 2014. Evaluating the barriers to specific industrial energy efficiency measures: an exploratory study in small and medium-sized enterprises. J. Clean. Prod. 82, 70–83. http://dx.doi.org/10.1016/j.jclepro.2014.06.057.

Chadha, A., 2011. Overcoming competence lock-in for the development of radical eco-innovations: the case of biopolymer technology. Ind. Innov. 18, 335–350. http://dx.doi.org/10.1080/13662716.2011.561032.

Combines, 2014. EPC Market Situation [WWW Document]. URL. http://www.combines-ce.eu/en-gb/projectindetail/epcmarketsituation.aspx.

De Almeida, A., Santos, B., Paolo, B., Quicheron, M., 2014. Solid state lighting review – potential and challenges in Europe. Renew. Sustain. Energy Rev. 34, 30–48. http://dx.doi.org/10.1016/j.rser.2014.02.029.

Delmas, M.A., 1999. Exposing strategic assets to create new competencies: the case of technological acquisition in the waste management industry in Europe and North America. Ind. Corp. Change 8, 635–671. http://dx.doi.org/10.1093/icc/8.4.635.

Dena, 2015. Energy-efficient Municipalities [WWW Document]. URL. http://www.dena.de/en/projects/building/energy-efficient-municipalities.html.

Dena, 2012. Abschlussbericht „Umfrage: Energieeffiziente Straßenbeleuchtung.

Difu, 2014. Finanzierung kommunaler Klimaschutzmassnahmen. Deutsches Institut fuer Urbanistik, Berlin.

DStGB, 2014. BILANZ 2014 und AUSBLICK 2015 der deutschen Staedte und Gemeinden (Deutscher Städte- und Gemeindebund, Berlin).

DStGB, 2010. Nr. 92-Öffentliche Beleuchtung, Analyse, Potenziale und Beschaffung (Deutscher Städte- und Gemeindebund).

Duscha, M., Brischke, L.-A., Schmitt, C., Irrek, W., Ansari, E., Meyer, C., 2013. Marktanalyse und Marktbewertung sowie Erstellung eines Konzeptes zur Marktbeobachtung für ausgewählte Dienstleistungen im Bereich Energieeffizienz.

EC, 2014. Energy Efficiency – Saving Energy, Saving Money [WWW Document]. URL. http://ec.europa.eu/energy/en/topics/energy-efficiency.

Edler, J., Georghiou, L., 2007. Public procurement and innovation—resurrecting the demand side. Res. Policy 36, 949–963. http://dx.doi.org/10.1016/j.respol.2007.03.003.

Edquist, C., Zabala-Iturriagagoitia, J.M., 2012. Public procurement for Innovation as mission-oriented innovation policy. Res. Policy 41, 1757–1769. http://dx.doi.org/10.1016/j.respol.2012.04.022.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14, 532–550. http://dx.doi.org/10.2307/258557.

Energy Transition, 2013. Local, Decentralized, Innovative: Why Germany's Municipal Utilities Are Right for the Energiewende [WWW Document]. URL. http://energytransition.de/2013/09/local-decentralized-innovative-why-germanys-municipal-utilities-are-right-for-the-energiewende/.

Fouquet, R., Pearson, P.J.G., 2006. Seven centuries of energy services: the price and use of light in the United Kingdom (1300-2000). Energy J. 27, 139–177.

Foxon, T.J., Pearson, P., 2008. Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime. J. Clean. Prod. 16, 148–161. http://dx.doi.org/10.1016/j.jclepro.2007.10.011.

Gallagher, K.S., Holdren, J.P., Sagar, A.D., 2006. Energy-technology innovation. Annu. Rev. Environ. Resour. 31, 193–237. http://dx.doi.org/10.1146/annurev.energy.30.050504.144321.

Gee, S., McMeekin, A., 2011. Eco-innovation systems and problem sequences: the contrasting cases of US and Brazilian biofuels. Ind. Innov. 18 (3), 301–315.

Gerring, J., 2004. What is a case study and what is it good for? Am. Polit. Sci. Rev. 2, 341–354. http://dx.doi.org/10.1017/S0003055404001182.

Guerzoni, M., Raiteri, E., 2015. Demand-side vs. supply-side technology policies: hidden treatment and new empirical evidence on the policy mix. Res. Policy 44, 726–747. http://dx.doi.org/10.1016/j.respol.2014.10.009.

Hall, S., Foxon, T.J., Bolton, R., 2016. Financing the civic energy sector: how financial institutions affect ownership models in Germany and the United Kingdom. Energy Res. Soc. Sci. 12, 5–15. http://dx.doi.org/10.1016/j.erss.2015.11.004.

Hannon, M.J., Bolton, R., 2015. UK local authority engagement with the Energy Service Company (ESCo) model: key characteristics, benefits, limitations and considerations. Energy Policy 78, 198–212. http://dx.doi.org/10.1016/j.enpol.2014.11.016.

Hannon, M.J., Foxon, T.J., Gale, W.F., 2013. The co-evolutionary relationship between Energy Service Companies and the UK energy system: implications for a low-carbon transition. Energy Policy 61, 1031–1045. http://dx.doi.org/10.1016/j.enpol.2013.06.009.

Hartmann, A., Roehrich, J., Frederiksen, L., Davies, A., 2014. Procuring complex performance: the transition process in public infrastructure. Int. J Op Prod. Manag. 34, 174–194. http://dx.doi.org/10.1108/IJOPM-01-2011-0032.

Helle, C., 1997. On energy efficiency-related product strategies—illustrated and analysed using contracting approaches in Germany as an example. Util. Policy 6, 75–85. http://dx.doi.org/10.1016/S0957-1787(96)00011-2.

Henriot, A., 2013. Financing investment in the European electricity transmission network: consequences on long-term sustainability of the TSOs financial structure. Energy Policy 62, 821–829.

Herring, H., 2006. Energy efficiency—a critical view. Energy, Second Bienn. Int. Workshop "Adv. Energy Stud." 31, 10–20. http://dx.doi.org/10.1016/j.energy.2004.04.055.

IEA, 2014a. Energy Efficiency Market Report 2014. International Energy Agency.

IEA, 2014b. Capturing the Multiple Benefits of Energy Efficiency. International Energy Agency, Paris.
IEA, 2013. Tracking Clean Energy Progress 2013. IEA, Paris.
IPCC, 2014. Climate Change 2014: Mitigation of Climate Change - IPCC Working Group III Contribution to AR5 (Int, Berlin).
Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: technology and environmental policy. Ecol. Econ. 54 (2–3), 164–174.
Jensen, J.O., Oesten, P., Nielsen, S.B., 2010. ESCO as innovative facilities management in Danish municipalities. In: EuroFM 2010: Research Symposium.
Kenney, M., Hargadon, A., 2012. Misguided policy? Calif. Manag. Rev. 54, 118–139. http://dx.doi.org/10.1525/cmr.2012.54.2.118.
Klein Woolthuis, R., Lankhuizen, M., Gilsing, V., 2005. A system failure framework for innovation policy design. Technovation 25, 609–619. http://dx.doi.org/10.1016/j.technovation.2003.11.002.
Kley, F., Lerch, C., Dallinger, D., 2011. New business models for electric cars—a holistic approach. Energy Policy 39, 3392–3403. http://dx.doi.org/10.1016/j.enpol.2011.03.036.
Köhler, J., et al., 2010. Infrastructure investment for a transition to hydrogen automobiles. Technol. Forecast. Soc. Change 77 (8), 1237–1248.
Lemon, M., Pollitt, M.G., Steer, S., 2015. Local energy policy and managing low carbon transition: the case of Leicester. UK. Energy Strategy Rev. 6, 57–63. http://dx.doi.org/10.1016/j.esr.2015.02.001.
Mantere, S., 2008. Role expectations and middle manager strategic agency. J. Manag. Stud. 45, 294–316. http://dx.doi.org/10.1111/j.1467-6486.2007.00744.x.
Marino, A., Bertoldi, P., Rezessy, S., 2010. Energy Service Companies Market in Europe - Status Report 2010.
Marino, A., Bertoldi, P., Rezessy, S., Boza-Kiss, B., 2011. A snapshot of the European energy service market in 2010 and policy recommendations to foster a further market development. Energy Policy 39, 6190–6198. http://dx.doi.org/10.1016/j.enpol.2011.07.019.
Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: towards an integrated framework. Res. Policy 37 (4), 596–615.
McKinsey, 2012. Lighting the Way: Perspectives on the Global Lighting Market, second ed. McKinsey&Company.
Mickwitz, P., Hyvättinen, H., Kivimaa, P., 2008. The role of policy instruments in the innovation and diffusion of environmentally friendlier technologies: popular claims versus case study experiences. J. Clean. Prod. 16, S162–S170. http://dx.doi.org/10.1016/j.jclepro.2007.10.012.
Mills, B., Schleich, J., 2014. Household transitions to energy efficient lighting. Energy Econ. 46, 151–160. http://dx.doi.org/10.1016/j.eneco.2014.08.022.
Nolden, C., Sorrell, S., 2016. The UK market for energy service contracts in 2014–2015. Energy Effic. 1–16. http://dx.doi.org/10.1007/s12053-016-9430-2.
Nolden, C., Sorrell, S., Polzin, F., 2015. Innovative Procurement Frameworks for Energy Performance Contracting in the UK Public Sector. SPRU Working Paper Series (SWPS) 2015–31, pp. 1–34.
Pätäri, S., Sinkkonen, K., 2014. Energy service companies and energy performance contracting: is there a need to renew the business model? insights from a Delphi study. J. Clean. Prod. 66, 264–271. http://dx.doi.org/10.1016/j.jclepro.2013.10.017.
Patton, M.Q., 2002. Qualitative Research and Evaluation Methods. SAGE, Thousand Oaks, CA.
Pint, E.M., Baldwin, L.H., 1997. Strategic Sourcing Theory and Evidence from Economics and Business Management.
Radulovic, D., Skok, S., Kirincic, V., 2011. Energy efficiency public lighting management in the cities. Energy, 5th Dubrovnik Conference on sustainable development of energy. Water & Environ. Syst. 36, 1908–1915. http://dx.doi.org/10.1016/j.energy.2010.10.016.
Roehrich, J., Lewis, M., 2014. Procuring complex performance: implications for exchange governance complexity. Int. J Op Prod. Manag 34, 221–241. http://dx.doi.org/10.1108/IJOPM-01-2011-0024.
Roehrich, J., Lewis, M., George, G., 2014. Are public–private partnerships a healthy option? a systematic literature review. Soc. Sci. Med. 113, 110–119. http://dx.doi.org/10.1016/j.socscimed.2014.03.037.
Rogers, E., 1995. Diffusion of Innovations.
SBI, 2013. Contracting zur Modernisierung der kommunalen Straßenbeleuchtung [WWW Document]. URL. http://licht.cfi21.org.
Schleich, J., 2009. Barriers to energy efficiency: a comparison across the German commercial and services sector. Ecol. Econ. 68, 2150–2159. http://dx.doi.org/10.1016/j.ecolecon.2009.02.008.
Schönberger, P., 2013. Municipalities as Key Actors of German Renewable Energy Governance: an Analysis of Opportunities, Obstacles, and Multi-level Influences. Wuppertal Papers 186.
Seawright, J., Gerring, J., 2008. Case selection techniques in case study research. Polit. Res. Q. 61, 294–308. http://dx.doi.org/10.1177/1065912907313077.
Selviaridis, K., Wynstra, F., 2015. Performance-based contracting: a literature review and future research directions. Int. J. Prod. Res. 53 (12), 3505–3540.
Singh, J., Limaye, D., Henderson, B., Shi, X., 2010. Procurement of Energy Efficiency Services – Lessons from International Experience. The World Bank, Washington DC.
Sorrell, S., 2007. The economics of energy service contracts. Energy Policy 35, 507–521. http://dx.doi.org/10.1016/j.enpol.2005.12.009.
Sorrell, S., 2005. The Contribution of Energy Service Contracting to a Low Carbon Economy. Tyndall Centre for Climate Change Research, Norwich, UK.
Sorrell, S., O'Malley, E., Schleich, J., Scott, S., 2004. The Economics of Energy Efficiency: Barriers to Cost-effective Investment. Edward Elgar Publishing, Cheltenham, UK.
Sovacool, B.K., 2009. The importance of comprehensiveness in renewable electricity and energy-efficiency policy. Energy Policy 37, 1529–1541. http://dx.doi.org/10.1016/j.enpol.2008.12.016.
Testa, F., Annunziata, E., Iraldo, F., Frey, M., 2016. Drawbacks and opportunities of green public procurement: an effective tool for sustainable production. J. Clean. Prod. 112, 1893–1900.
Toffel, M.W., 2002. Contracting for Servicizing. Unit Research Paper. Harvard Business School Technology and Operations Mgt., 08–063.k.
Transparense, 2013. D2.1 European EPC Market Overview.
Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L., Yeow, J., 2014. Barriers to innovation through public procurement: a supplier perspective. Technovation 34, 631–645. http://dx.doi.org/10.1016/j.technovation.2014.04.003.
van Soest, D.P., Bulte, E.H., 2001. Does the energy-efficiency paradox exist? technological progress and uncertainty. Environ. Resour. Econ. 18 http://dx.doi.org/10.1023/A:1011112406964.
Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive "failures" framework. Res. Policy 41 (6), 1037–1047.
Williamson, O.E., 1985. The Economic Institutions of Capitalism. Free Press, New York.
Wilson, C., Grubler, A., Gallagher, K.S., Nemet, G.F., 2012. Marginalization of end-use technologies in energy innovation for climate protection. Nat. Clim. Change 2, 780–788. http://dx.doi.org/10.1038/nclimate1576.
Yin, R.K., 2009. Case Study Research: Design and Methods. Sage Publications, Inc, Thousand Oaks, CA.
ZVEI, 2015. Die Lichtbranche - Fakten, Forderungen, Zahlen. ZVEI, Frankfurt am Main.