Realizing Energy Savings in the Public Sector

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Abstract

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Problem: Energy prices are increasing at a high rate, eating away at the municipalities' operating budgets. With every energy efficiency investment opportunity that is bypassed, tax money is wasted. An investment in new street lighting technology presents financial, environmental and social benefits, yet few municipalities are replacing their lighting installations with more energy efficient technology. It is thereby interesting to look closer at the barriers hindering energy efficiency investments within municipalities.

Purpose: The overarching purpose of this thesis is to identify the most critical barriers hindering energy efficiency investments in local governments in Sweden, and provide practical solutions to the same. For this purpose, we examine municipal settings in order to understand the environment in which decisions are made. To identify and evaluate the barriers we exemplify an energy efficiency investment with one in public street lighting, in which we assess the latest developments within lighting technology and their benefits.

Methodology: Initially, a broad and explorative pre-study was conducted in order to gain more wide-ranging knowledge of the problem area. This was followed by a case study covering five different municipalities, aiming at identifying barriers to energy efficiency investments. We had an explorative view towards the problem, encouraging the use of a qualitative research strategy through open, individual interviews with municipal officers and local politicians.

Conclusions: Energy performance contracting, together with a life cycle value approach, targets the barriers – *lack of investment capital*, *shortsighted investment horizon*, and *technology ignorance*. *Insufficient procurement competence* must be targeted by legislative authorities through clearer guidelines of how to apply functional procurement within the Swedish Public Procurement Act.

Key Words: Energy performance contracting, managed street lighting, life cycle value, energy efficiency, public sector.

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Table of Contents

1 Introduction

In this chapter, we present the purpose of the thesis, and motivate why energy efficiency investments in local governments are both necessary and interesting to explore.

1.1 Background

The member states of the EU currently use around 1 725 Mtoe (Megatons of oil equivalent) of energy per year, corresponding to an annual sum of more than EUR 1000 per person.[1] The price of energy has increased in real terms by roughly three percent per year over the last decade.[2] While energy is becoming more expensive, resources such as fossil fuels are also becoming more and more scarce. According to many experts, known oil reserves will only be able to sustain present production rates for another 40 years.[3]

Energy use is also a major contributor to climate change, which is a cause of increasing concern in recent years. Energy is the source of 4/5 of total greenhouse gas emissions in the EU. Despite these concerns, much of this energy continues to be wasted, whether by inefficient equipment or due to lack of awareness by energy users.[4]

These concerns do not only exist within the EU. The North American Electric Reliability Council (NERC) estimates that demand for electricity in the U.S. will increase by over 19 percent during the next decade. However, the electric capacity is projected to grow by only six percent during the same period. It will be very difficult to even out this supply-demand imbalance in time by simply expanding the generating capacity. Instead, efforts must concentrate on conserving energy on the demand-side through energy efficiency.[5]

One role of public authorities (states, administrations, local authorities) is to make individuals and their political representatives aware of the urgency of improving energy efficiency.[6] According to the European Parliament's directive on energy end-use efficiency[7], the local governments should also be role models in terms of energy efficiency. One opportunity for the local governments, and particularly the municipalities, to address the demand-side of this issue is to save electricity through technological upgrades to municipal street lighting.

[1] European Commission (2005), p. 39
[2] http://www.scb.se, 2008-03-18
[3] European Commission (2005), p. 35
[4] Ibid
[5] North American Electric Reliability Council (2006), p. 6
[6] European Commission (2005), p. 35
[7] Directive 2006/32/EC of the European Parliament and the Council

Street lighting installations are vital assets for a municipality, providing safe roads, inviting public areas, and enhanced security in city centers and homes. However, lighting installations consume large amounts of energy, contributing to high operating costs. Electricity used for outdoor lighting accounts for roughly 40 percent of a municipality's total electricity use in many European cities. In times of rising energy prices and constrained budgets, local governments need to find ways to contain their expenses and limit local taxes, while increasing the level of service and security they provide to local citizens.[8] By investing in modern, less energy consuming, technologies in public lighting installations, a municipality could contribute to more efficient use of energy, decreased maintenance costs, as well as the reduction of CO_2 emissions, as required by the Kyoto Protocol, the Bali climate summit, and the European Parliament's directive on energy end-use efficiency and energy services.[9]

As seen in the city of Oslo, which has pioneered the deployment of new streetlight technology in Europe, cities that take advantage of today's new technologies and solutions can reduce the overall costs associated with streetlight networks by almost 50 percent, while increasing the quality of service and safety.[10]

In Sweden, the cost of maintenance and operation of street lighting within municipalities amounted to a total of SEK 1 185 million in 2005, an increase of nine percent since 2003. This cost increase is mainly attributed to rising energy prices.[11] At the same time, around 50 percent of the street lighting technology within Sweden's municipalities consists of outdated, energy-inefficient lamps and luminaires.[12] This accounts for a large energy and cost savings potential, yet many municipalities are either hesitant in switching to new technology, or do not have the right tools to identify this potential.

In a wider scope, an investment in energy efficient street lighting installations is really an example of an investment aiming at reducing a municipality's operating and maintenance budget, given that the majority of the costs of such technology lie in energy use and maintenance. Since the price of energy has increased beyond the rate of inflation the last few years, and may well continue to do so, these kinds of investments should be prioritized in order for municipalities to contain local taxes, and rationalize the use of these funds. It is therefore interesting to look closer at the barriers that hinder cost reducing investments, such as energy measures, in municipalities.

1.2 Issue of Study

Considering the above highlighted financial, environmental, and social benefits that an investment in new street lighting technology could bring about, why then are not

[8] Echelon Corporation (2007), p. 3
[9] European Commission (2005), pp. 29-32
[10] Mjos, T. (2006), p. 7
[11] http://www.skl.se, 2008-04-14
[12] http://www.ljuskultur.se, 2008-02-14

more municipalities replacing their lighting installations with more energy efficient technology?

Previous research conducted by SPRU (Science and Technology Policy Research), a UK based center for research in the field of science, technology, and innovation, has compiled the work of several researchers that have studied barriers to energy efficiency.[13] Two of the most dominant researches in this field, Adam B. Jaffe and Robert N. Stavins, have identified a number of potential barriers consisting of, for example, access to capital, split incentives, and bounded rationality.[14] Another researcher, Catherine Cooremans, has examined the drivers of businesses' energy efficiency investments, predominantly from a cultural perspective. Cooremans formulates three hypotheses for why energy efficiency is not prioritized in businesses: (1) energy efficiency investments are not perceived as strategic, (2) cultural dimensions may explain why they are not seen as strategic, and (3) the level of energy management is an important driver of investment decisions. These hypotheses have largely been confirmed by the preliminary results of Cooremans' study.[15]

Common to this previous research is a large focus on identifying barriers, and less on providing solutions to these barriers. A recent Swedish Government Official Report focuses on recommendations for how the state government can utilize instruments of control in order to alleviate energy efficiency barriers[16]. However, there is a lack of *practical solutions* that local governments can utilize in overcoming barriers. Furthermore, considering the range of potential barriers previously identified, it is interesting to identify those that are the *most critical* within local governments, and propose solutions to the same.

Within municipalities, politicians are the primary decision-makers. Here, societal interests such as education, healthcare, and public welfare are expected to be in the forefront.[17] It may be hard to argue that the economic rationality behind an energy efficiency investment should be prioritized before increased welfare or better education, but what if the money saved will eventually pay for the increased welfare? One can argue that the choice of investing in energy efficiency is at the same time an investment in education; the money saved on energy today will pay for the school tomorrow. This decision is further motivated if energy prices continue to increase.

Although the main strategy of a commercial organization - to maximize profits – does not have an obvious counterpart in the public sector, public organizations such as municipalities still act in competitive environments in which resources for funding are scarce and require great legitimacy from key stakeholders.[18] Therefore, a lack of investment funds could be a significant barrier. Politicians are ultimately responsible

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[13] http://www.sussex.ac.uk/spru, 2008-01-20
[14] Jaffe, A. & Stavins, R. (1994), p 2
[15] Cooremans, C. (2007), pp. 78-81
[16] Statens Offentliga Utredningar (2008), pp. 61-92
[17] Mattisson & Thomasson (2007), p. 441
[18] Ibid

for the allocation of municipal funds. One cannot perhaps expect politicians to have the technical competence to initiate an investment in new lighting technology. Instead, this initiative should come from those most knowledgeable within the field of street lighting. It is therefore of relevance to investigate whether this knowledge is present within municipalities, and if it is effectively communicated to the final decision maker.

The possible barriers above are internally created, and therefore the accountability, and capacity to solve them, should lie within the boundaries of the municipality. However, municipalities do not exist in an isolated environment, but are influenced by both government and private organizations alike. Thus, some of the barriers hindering energy efficiency investments might be beyond a municipality's area of jurisdiction. If this holds, the influence of external stakeholders, such as legislators and energy service companies, also needs to be attended to in order to overcome all barriers.

1.3 Purpose

The overarching purpose of this thesis is to identify the most critical barriers hindering energy efficiency investments in local governments in Sweden, and provide practical solutions to the same. For this purpose, we examine municipal settings in order to understand the environment in which decisions are made. To identify and evaluate the barriers we exemplify an energy efficiency investment with one in public street lighting, in which we assess the latest developments within lighting technology and their benefits.

1.4 Target Audience

The primary stakeholders have had a decisive impact on the scope and direction of the thesis, of which they are also the prime beneficiaries. These are our tutors, the program leaders of Technology Management, WSP Group, and local politicians and municipal officers in Sweden.

The secondary stakeholders have had no formal influence on the thesis, yet our findings can be of significant value as to filling knowledge gaps and suggesting actions towards realizing energy efficiency. These are Energy Service Companies and other solution providers, policy makers such as the Swedish National Energy Agency, and the students of Lund University. The study is also relevant in the context of implementing the directive on energy end-use efficiency and energy services into Swedish legislation[19].

[19] Directive 2006/32/EC of the European Parliament and the Council

2 Methodology

This chapter explains the process by which the results of this thesis have been obtained. In addition, the components of the theoretical framework and their interrelation are presented.

2.1 Work Process

In this thesis we used street lighting technology to exemplify an energy efficiency investment. This choice was based on the fact that, of Sweden's 2,1 million streetlights, 50 percent currently consists of outdated and energy inefficient technology[20]. We saw compelling benefits of replacing these with newer technology. However, we first needed to acquire a greater understanding of the problem area, and thereby develop a clearer image of where to position the focal point of our thesis. Thus, the first phase of our work process was to engage in a broad pre-study, as seen in figure 1.

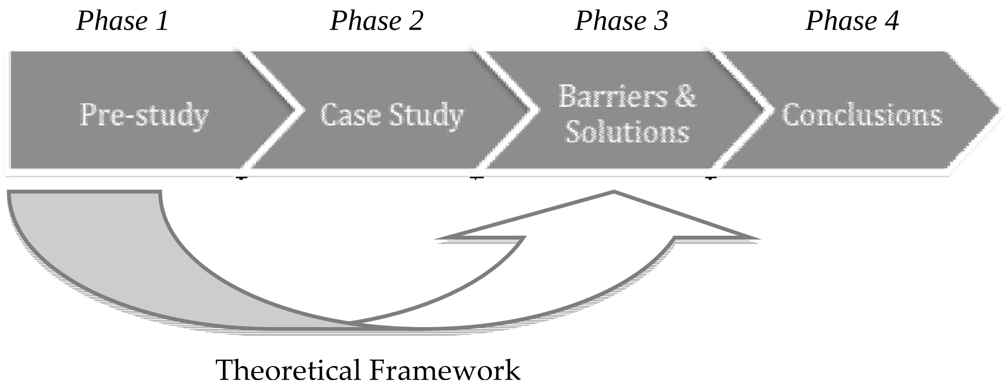

***Figure 1** Work process overview*

We first and foremost identified the key stakeholders involved in public street lighting and its management. This was important in order to determine the structure and assignment of responsibilities among them. It also provided support in designing our case study and choice of interviewees. We also needed to estimate the potential in financial, social, and environmental terms, of investing in new lighting technology, in order to appreciate possible incentives, or lack thereof, for the parties involved. Finally, we identified the lighting technology currently available and under development, in order to make an assessment of the leading technology with greatest investment value.

During the course of our pre-study, we obtained insights into possible barriers that may help explain why cost reducing investments are not being pursued by municipalities to a further extent. In order to obtain more reliable, primary, data, we

[20] Telephone interview with Magnus Frantzell, 2008-02-21

undertook a case study in the second phase, in which we applied the investment potential in energy efficient streetlight technology identified in phase one to five different municipalities. We then interviewed the key decision-makers involved in this type of investment decision in each of the municipalities, with the aim of strengthening our understanding of the barriers hindering these investments.

In the third phase – barriers and solutions – we have discussed and categorized the barriers based on the empirical support from our case study. Relevant theories have been chosen in order to provide additional understanding of the barriers, as well as to provide support for the solution-oriented strategies that follow.

In the final phase, we have provided concluding recommendations, summarizing the key arguments from the prior phase. Additionally, we have discussed the extent to which our findings can be generalized and applied to other cost reducing investments.

2.2 Theoretical Discussion

The theoretical framework has been constructed recursively throughout phase one, two, and three of the work process. As mentioned earlier, relevant theories have been chosen to provide additional understanding of the identified barriers, as well as to provide support in constructing strategies aiming at overcoming these barriers.

Figure 2 illustrates the composition of the theoretical perspectives that together make up the theoretical framework. Public strategic logic provides the structural context of the theoretical approach, and is composed of three different logics – political, professional, and commercial – that are present within strategic municipal decision-making. Understanding this division of logics is essential as employees on different levels within a municipality are likely to have different prioritizations, which in turn will influence the identified barriers. Within this context, three different theoretical perspectives are chosen to give further clarification of the identified barriers.

Technology adoption concerns the critical steps along the path of new technology adoption in a marketplace. Procurement uncertainty highlights the lack of certain information in purchasing decisions that may cause discouragement from procuring new technology. Total cost of ownership and life cycle cost are principles that emphasize a long-term perspective in order to make accurate valuations in purchasing decisions. Finally, EPC (energy performance contracting), a business model that uses cost savings from reduced energy use to finance the cost of installing energy conservation methods, is a central component of the theoretical framework, containing solution-oriented techniques aiming at overcoming the previously identified barriers.

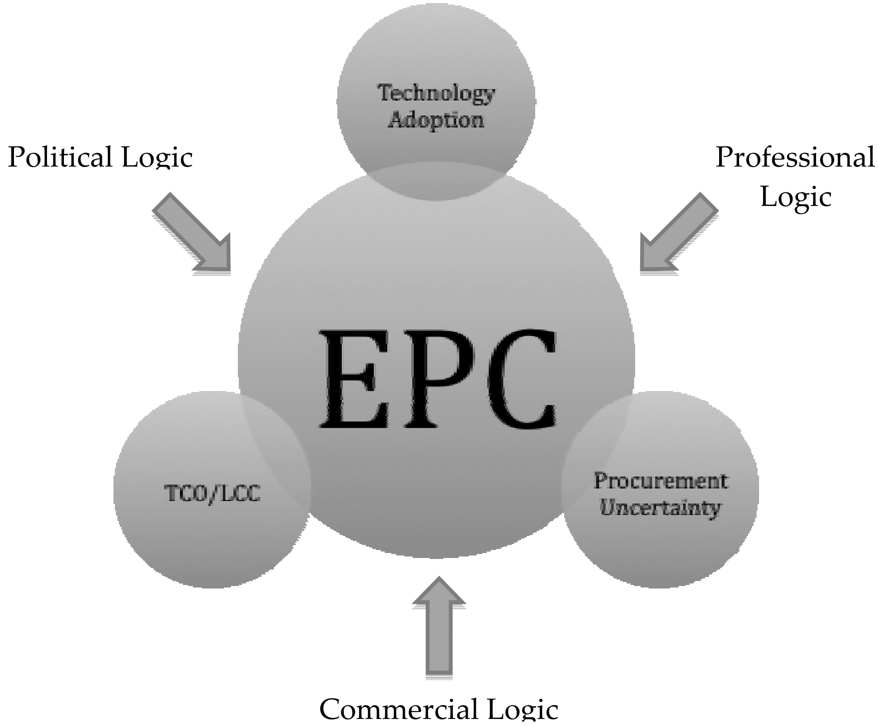

Figure 2 *Elements of the theoretical Framework*

2.3 Methodological Approach

One of the means of fulfilling a sound methodological approach is through the objective of creating a unifying fit between the three areas: paradigm, solving techniques, and problem.[21] The paradigm concerns the researcher's basic assumptions, which constitute his or her view of reality. This view, in turn, influences how the researcher perceives a given problem, or research question. The problem should determine which solving techniques that are utilized[22] and together the harmonious fit of the three pillars constitutes the methodological approach.[23]

Historically, three main paradigms have guided research within social sciences: the positivistic, systems theoretical, and interpretive paradigm.[24] The paradigms differ, among other things, in their positions regarding the objectivity of reality in relation to the individual and his or her perception of that reality. The interpretive paradigm lies farthest from the conception of an objective reality, and holds that reality is a social construction dependent on the subjective interpretation of individuals. Therefore, the

[21] Bjerke (1981), p. 2 and Nilsson (1994), p. 1
[22] Nilsson (1994), p. 13 and Jacobsen (2002), p. 56
[23] Bjerke (1981), p. 3
[24] Ibid

role of the researcher is to study how individuals interpret and give meaning to social phenomena in order to gain knowledge of reality[25].

Parallels can be drawn between the interpretive paradigm and our view of the research question at hand. In order to create an understanding of how investments of this nature are approached by public organizations, it is imperative that we target the rationality of the individuals involved in the decision-making process in public organizations. Since this is an area fairly unchartered by business research, we have had an explorative view towards the problem, fostering the use of a qualitative research strategy.

2.4 Qualitative Research Strategy

The qualitative research strategy primarily aims to interpret, understand, and go to the depth of a given situation or phenomenon. It is often an appropriate approach when the desire is to create clarity in a field in which the researcher has little or no prior knowledge.[26] The qualitative research strategy is characterized by a close proximity to the subject being researched, and by a considerable degree of flexibility. This flexibility is distinguishable in two different ways. The first concerns the experience gathered during the research process. If certain questions have been expressed incorrectly or left out altogether, the researcher has the ability to correct this during the process. Secondly, the way that the research subject is approached is flexible in terms of which questions are asked, and in what order.[27]

We have utilized a qualitative research strategy as we felt it necessary to approach the empirical research with an open mindset in order to obtain the research subject's own perception of his or her reality. We did not want to categorize the information to be collected beforehand, as this might not have led us to a truthful representation of the interviewee's thoughts. Also, our goal was to acquire a greater understanding of a complex phenomenon, and thereby be open to new information and interpretations, giving additional grounds for the use of a qualitative research strategy.

2.5 Data Collection

During the course of our research, data has been gathered from both primary and secondary sources. Primary data is data collected by the researcher directly from the source at hand, whereas secondary data is based on interpretations of primary data, and thereby consists of information that has been gathered by someone else.[28] In our research, primary data has consisted of interviews, both face-to-face and over the telephone. Secondary data has been accumulated from texts of various natures.

[25] Jacobsen (2002), p. 33
[26] Ibid, p.145
[27] Holme & Solvang (1997), p. 80
[28] Jacobsen (2002), pp. 152-153

2.5.1 Pre-study

During our pre-study, many interviews with one of our tutors, Daniel Svensson, were initially conducted. Through his experience of working side by side with municipal organizations, Daniel provided much help in the process of identifying the key stakeholders involved in public lighting; particularly the organizational decision-making chain, and the implicated municipal members, involved in a potential investment decision in new streetlight technology.

A large number of telephone interviews were carried out with legislative and policy-making organizations such as the Swedish Competition Authority and the Swedish Energy Agency, municipal project managers of successfully undertaken street lighting projects, as well as various suppliers of streetlight technology. These interviews generally took the form of open-ended discussions, without any formal agenda. However, certain questions were formulated in advance and kept in mind in order to provide initial direction to the interviews.

In order to acquire a wide-ranging knowledge base, a technique known as snowball sampling was used. This technique is characterized by the recruiting of future interview subjects from the acquaintances of existing study subjects[29]. Thereby, we generally concluded our interviews by asking for recommendations of other people knowledgeable within the same area. This was a way of quickly obtaining a holistic view of the area, as well as providing us with multiple views of certain issues, allowing us to critically assess the obtained information.

In addition to the interviews, much information has been gathered from relevant books, articles, reports, conference proceedings, and websites.

2.5.2 Case study

The use of a case study, or the study of a certain phenomenon within a specific context, is useful when the aim is to acquire a deeper understanding of a certain event, and to describe what is specific to this event within a certain context[30]. In this case, we focused on an investment in public streetlight technology as an example of a cost reducing, energy efficiency investment, within the context of municipalities.

In our analytical approach, we chose to focus on the derivation of generalizations, because we find it necessary, from a research perspective, to be able to reach conclusions that are valid for more than just one specific entity. Thus, we selected a number of five different municipalities as units of study, consisting of Landskrona, Klippan, Kristianstad, Hässleholm, and Lund, the empirical findings from which have been compared and contrasted in order to reach our conclusions. In addition, the empirical information gathered from the interviewees has been anonymized, with the aim of inciting them to express themselves freely, thereby generating more honest and truthful answers.

[29] Jacobsen (2002), p. 201
[30] Ibid, p. 98

The choice of municipalities was based on as equal grounds as possible, in order to support our aim of obtaining more widespread results. Municipalities with more than 4000 lighting points were chosen, as we appreciated anything lower to be unprofitable in terms of the resources required in order to make a wide scale replacement for new technology. Also, all municipalities were chosen within the same landscape, as the hours of runtime per lighting point vary across the country.

Within each municipality, the choice of interviewees was based upon the decision-making chain previously identified in the field study, shown in figure 3. In respect of availability, our choice of interview subjects consisted of an operating technician, the head of the technical administration, and a local politician; representative of either the municipal executive board or the technical committee. In total, we performed a number of 15 interviews.

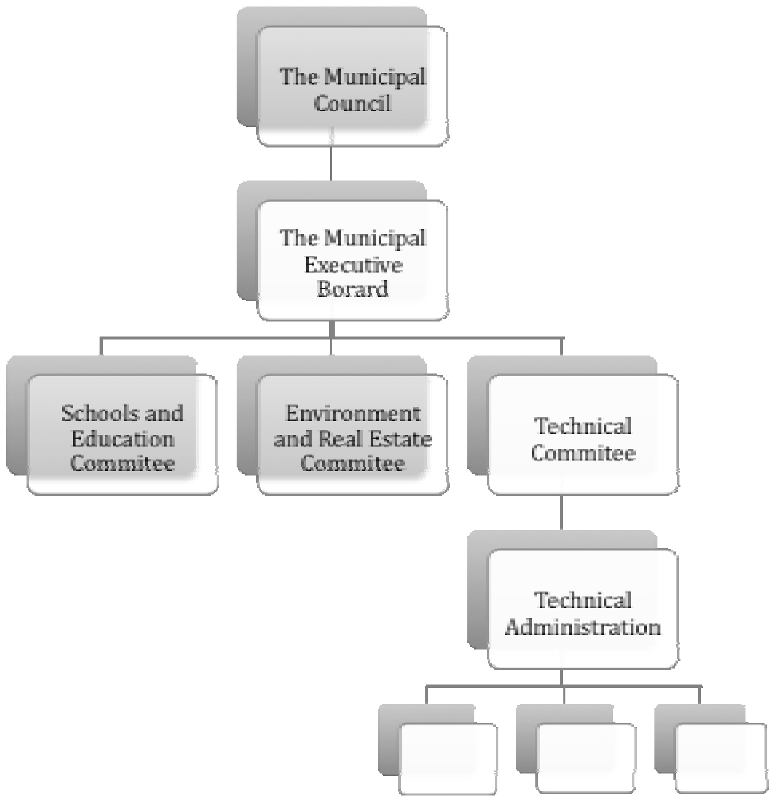

Figure 3 *Example of a municipal organizational structure*

In accordance with our qualitative research strategy, open, individual interviews were conducted with each of the research subjects. This form of interview is appropriate for obtaining the subject's own interpretations and thoughts on a given topic, and is characterized by a low degree of formality and few predetermined alternatives of reply.[31] For each of these interviews, open-ended questions were prepared in advance, providing a certain degree of structure and direction. However, the order in which the questions were asked varied from interview to interview, depending on how the dialogue progressed. We wanted the interviewee to speak freely, and not limit his or her thoughts to a certain sequence of questions.

In order to document our findings as closely as possible, the roles of interviewer and note taker were divided among the two of us. The notes were reviewed and summarized in close succession to the interviews, with the intention of not forgetting important details. In the case of identified gaps in the empirical findings, follow-up interviews were conducted over the telephone to obtain the necessary information.

2.6 Methodological Reflections

As our empirical findings are based on the opinions of the interviewed municipal officers and local politicians, it is highly possible that our results contain elements of bias. We have tried to limit this aspect by concentrating on the most critical barriers, i.e. the barriers for which we have found strong empirical support across a number of the municipal cases, and that we believe are most significant in explaining why municipalities are not pursuing energy efficiency investments to a further extent.

Although we have had the ambition to approach the case study interviews with an open mindset in order to minimize our influence on the interviewee, and thereby gain insight into his/her own perspective on the subject, we are well aware of the practical difficulty of this aim. Prior to the case study interviews, we had obtained a rough idea of what the most critical barriers might be through discussions with our tutor Daniel Svensson, as well as industry representatives. We tried to limit the effect of these preconceptions by utilizing open-ended questions to which the interviewees could provide their personal views. Furthermore, preconceptions to which we did not find empirical support in the case studies where not regarded as critical barriers.

[31] Jacobsen (2002), pp. 160-161

3 Theoretical Framework

The following chapter presents the theories incorporated in the theoretical framework in greater detail, including the Energy Performance Contracting business model that constitutes a major part of our proposed solutions in chapter 9.

3.1 Public Strategic Logic

This section and its subchapters are based on "Kommunala huvudmannastrategier för kostnadspress och utveckling – en studie av kommunal teknik"[32]. According to legislation, a municipality is the responsible authority for the activities it carries out. In this context, politicians are ultimately responsible for establishing organizational policies and goals. In a municipality, there are two ways of making the political arena operative and executing these goals: through the internal hierarchy and external market. The former implies the use of professional staff from the municipal administration, and the latter involves purchasing production capacity from external, commercial suppliers. Thereby, municipal strategy involves three different players - political, professional, and commercial players. Each of these players, in turn, constitutes a separate logic, and a given municipal strategy will therefore be based upon, and contain elements of each of these rationales.

3.1.1 Political Logic

The political logic has its main arena amongst the competition with political objectives advocated by other players. The municipal strategy will aim to strengthen the opportunities of fulfilling political goals of different kinds. For example, the political predecessor might try to maximize the number of acquired votes, realize the ideological objectives, realize a few objectives at the cost of others, or prevent other's ideologies from being realized.

When an individual cannot fulfill all of his/her objectives, the person must prioritize among them, and interact with other players accordingly. This interaction can be exercised through either compromise or tradeoffs. When compromising, the parties meet each other halfway in order to achieve a mutual understanding. When utilizing tradeoffs, one party will deviate from his/her preferences in a question of lesser importance, given that this party will obtain the same service in return. The result, in a large number of cases, is that solutions will have support from a majority of the people involved, but will not be synonymous with any single party's particular order of preferences.

Although the political content can never be formally regulated, certain procedures must be followed in order to foster democratic values and principles. In practice, this means that all activities must be carried out with full insight from the general public. This can have an adverse affect on the innovative climate in a municipality. Subjected to public scrutiny, decision-makers might want to minimize the risk of failure by refraining from experimentation and strictly adhering to established routines and

[32] Mattisson (2000), pp. 131-141.

norms. This form of action thereby hampers the innovative development within a municipality.

3.1.2 Professional Logic

The role of the municipal administration, consisting of professionals, is to account for the operative implementation of the main prioritizations established on the political level. Inversely, professional assessments often constitute a foundation for political decisions, creating a mutual dependence between the two functions. The work of the professional is characterized by a high degree of autonomy regarding, for instance, the technology and methods used, and requires a substantial level of expert knowledge in order to be fulfilled.

The technical administration does not only have to answer to technical issues, but must act in other regards as well. Its actions must account for political concerns, or the local popular will, but must also meet the numerous private entrepreneurs who offer their services based on commercial grounds.

3.1.3 Commercial Logic

In addition to the municipal administration of professionals, the local politicians can choose to acquire resources and services from external suppliers. The external supplier interacts with the municipality on a voluntary basis, within the boundaries legally stipulated by politicians, and the municipality is responsible for making sure that the activities meet the democratic principles.

As in the case of political decision-making, commercial players must also prioritize, the logic behind which, however, is based on risk and return. The commercial organization acts under more clear-cut circumstances, where rational principles solely govern the organizational goals. A municipality is ascribed a commercial logic when turning to commercial organizations, because as the latter acts on a voluntary basis, the municipality must be able to meet the requirements for the commercial organization to want to engage in a business transaction.

Coalitions and compromise occur, as in the political context, but since the ultimate goal of profit maximization is universally applicable across all industries, these coalitions concern more so the means of achieving this goal. In a political organization, both means and ends can be the basis of compromise, increasing the risk of vague operative instructions regarding prioritizations when implementing tasks.

The decisions and actions taken within a municipality can be regarded as a composition of tasks within these three means of reasoning. Together, they are expected to account for democracy, efficiency, and professional assessments. Depending on the situation in which a given decision is made, the relative weight that each of logics constitute will vary. However, they are jointly expected to contribute to the municipality’s ability to fulfill the local inhabitants’ requirements in an adequate and cost efficient manner.

3.2 Total Cost of Ownership and Life Cycle Costing

3.2.1 Purpose and Method of Calculation

The purchase of most major equipment involves the expenditure of a substantial amount of money. The purchase price for a piece of equipment, however, is frequently overshadowed by other elements of cost. Since capital equipment is often used for many years, the cost of operation and maintenance during its lifetime may far exceed its initial cost. Although estimating operating and maintenance costs that will be incurred in future years is not easy, such costs will be incurred and must be addressed when comparing the total cost of ownership (TCO) of two or more items of equipment which will satisfy an organization's needs.[33]

The concepts of total cost, life cycle costing (LCC) and TCO are very closely related. Charles K. Coe, in his article, *Life Cycle Costing by State Governments*, defines LCC as, "a purchasing process that considers the total cost of ownership of a commodity", suggesting that they are, in fact, identical. The concepts all suggest that the supply managers adopt a long-term perspective instead of a short-term, initial-price perspective, for the accurate valuation of buying situations.[34] TCO includes three components: *acquisition costs*, *ownership costs*, and *post-ownership costs*. Acquisition costs, such as purchase price and financing costs, are the initial costs associated with the purchase, and represent an immediate cash outflow. Ownership costs are associated with the ongoing use of the equipment, including such costs as energy usage, scheduled maintenance, repair, and downtime. The sum of these costs may well exceed the initial purchase price and have significant bearing on cash flow and profitability. Hence, understanding and minimizing these costs can have strategic significance. Lastly, post-ownership costs are composed of salvage value and disposal costs, and can thereby be estimated as either cash inflows or outflows.[35]

Coe further discusses the use of LCC in the context of energy conservation. In implementing the LCC process, governments can chose between modified and total LCC. Modified LCC considers only purchase price and energy use. Total LCC, however, consists of a series of eight steps.[36] The steps are shown in Table 1.

[33] Burt et al (2003), p. 262
[34] Ferrin et al (2002), p. 18
[35] Burt et al (2003), pp. 164-169
[36] Coe (1981), p. 565

Table 1 *LCC procedure*[37]

1. Estimate useful life of item
2. Estimate operating and maintenance costs
3. Estimate salvage value of item
4. Subtract salvage value from cost of owning item
5. Obtain total life cycle cost by adding cost of acquisition to amount calculated in step 4
6. Repeat steps 1-5 for each item being considered for purchase
7. Compare the total life cycle cost of items under consideration
8. Purchase least expensive item

In estimating the useful life and operating and maintenance costs of an item, governments have three options. One way of doing this is by requiring the potential suppliers to estimate the costs, and, where possible, warrant their accuracy in the contract. After estimating the useful life and costs of owning the equipment, the next step in LCC is to estimate the salvage value, or the amount that can be reasonably expected to be received for the item at the end of its useful life, and subtract this amount from the cost of owning the item. In many cases, the salvage value of competing items will be roughly the same, and therefore, does not need to be factored in the LCC calculation. The fifth step in the LCC process entails obtaining the total life cycle cost by adding to the acquisition cost the ownership cost less the salvage value cost. The total life cycle cost of each item is compared and the least expensive item is bought.[38]

3.2.2 Barriers to Performing LCC

Few governmental institutions incorporate LCC into their procurement process. According to Coe, an imposing array of psychological, structural, and procedural barriers limit them in the use of LCC.

Psychological resistance and fear of change is the most prominent obstacle. State and local purchasing statues typically require that items be purchased from the lowest responsible bidder. Many local governments feel that these are legal impediments to implementing energy-efficient procurement programs, and are thereby hesitant to use LCC because of potential legal tangles. Another concern is the reluctance of elected officials to award contracts to vendors offering goods with higher acquisition costs than comparable goods of competing vendors, because of the fear of political repercussions from citizens unaware of all the factors considered in the LCC process.[39]

[37] Coe (1981), p. 565
[38] Ibid, p. 565-566
[39] Ibid, p. 567

A major structural barrier is the existence of decentralized purchasing systems. Several local governments permit each department to do its own purchasing. In this autonomous state, convincing each agency of the merits of LCC becomes very difficult.[40]

Many governments are simply not sophisticated enough to carry out LCC, particularly at the local level. Another procedural barrier for many local governments is the way the budget appropriation process operates. A fixed appropriation is often made for a given number of units, an approach that does not provide the flexibility needed for LCC.[41]

3.3 Procurement Uncertainty

The procurement of new technology implies the incorporation of a new product or service into the customer's existing organization. If it is not a question of a simple replacement of worn-out equipment, the procurement entails an organizational change. This change will displace the state of equilibrium and create uncertainty. Depending on the nature of the uncertainty, the customer will search for different kinds of information to minimize it. Uncertainty in procurement can be categorized into three different groups: *application*, *functional*, and *political uncertainty*.[42]

Application uncertainty arises when the customer is afraid that the product will be difficult to incorporate into existing operations. Although the client relies on the functional aspects of the product, he or she is afraid of problems during the installation or maintenance of the product, or difficulties in training operators. The marketer of the product can minimize the uncertainty by providing an initial trial period, training, guarantees, or service.[43]

Functional uncertainty implies that the customer is afraid that the product will not meet his or her requirements. Functional uncertainty can be minimized through guarantees, demonstrations, and statistics.[44]

Political uncertainty arises when the decision-maker in the client organization is worried that the organizational change induced by the procurement will lead to opposition from other groups, such as the labor union or the customers of the client organization. The marketing organization must, in order to sustain political calm, communicate thoroughly with these groups. Table 2 provides an overview of the information that can minimize the different uncertainties.[45]

[40] Coe (1981), p. 567
[41] Ibid
[42] Guillet de Monthoux (1975)
[43] Ibid
[44] Ibid
[45] Ibid

***Table 2** Information minimizing procurement uncertainties*[46]

Application Uncertainty	Functional Uncertainty	Political Uncertainty
Maintenance	Performance	Customer experiences
Operator training	Operational reliability	Flexibility of use
Installation	Service	Financing solutions

3.4 Technology Adoption

In general, markets move toward technologies that provide a net improvement in social welfare – such as the transition from steam to diesel locomotives, or from black and white to color television. Occasionally, however, market dynamics are not sufficient to reach a desired objective that is projected to be in the greater social interest. Many reasons may help explain why a market resists this change, for example, lack of familiarity with a technology, perceived risks, or a higher initial purchase price. In the last-mentioned case, customers may not be aware of the lower life cycle cost associated with a more expensive, higher efficiency product. When such market failures occur, market transformation programs can facilitate greater levels of market adoption of a certain technology through the reduction or elimination of these barriers.[47]

The Office of Energy Efficiency at Natural Resources Canada together with Navigant Consulting has developed the 5A's framework, a tool to identify market penetration barriers affecting new technologies. The framework considers all the steps a product follows as it moves from manufacturer to the end user, starting with *availability* of a technology and moving through to *end user acceptance*, as seen in figure 4.

***Figure 4** The Stages of the 5A's barrier analysis tool*[48]

Each step in the framework represents a critical aspect of the market adoption path for a new technology. The first step, availability, addresses the existence of a technology for market transformation. The second step, awareness, evaluates to what extent the market participants, such as distributors, retailers, and end users are aware of the more efficient market technology, and concerns the documentation of benefits, policy, and market intelligence. In the case of new streetlight technology, this step would, for example, address whether or not the energy savings and quality aspects are well documented, and the extent to which the regulatory environment supports the use of the technology. Accessibility is the third step, concentrating on the flow of products, technologies, and information. If a technology is available and people are aware of its

[46] Guillet de Monthoux (1975)
[47] Delve & Wilkins (2002)
[48] Ibid

existence, the market needs to have easy access to purchasing the technology. The fourth step in the framework is affordability, where a higher sales price might pose a barrier to market adoption of a given technology. This is particularly true in sectors where consumers are highly first-cost sensitive. The final step, acceptance, combines elements of the preceding four steps with other factors influencing the purchasing decision, such as form, fit, and function of the product or technology.[49]

3.5 Energy Performance Contracting (EPC)

3.5.1 Business Logic

In an energy performance contracting project, a client enters into an agreement with an energy service company, commonly referred to as the ESCO, a contractor that develops, installs, and possibly arranges financing for projects designed to improve the energy efficiency and maintenance costs of a system or a combination of systems. The ESCO identifies and evaluates energy-saving opportunities and then recommends a package of improvements to be paid for through these savings. The ESCO will guarantee that savings meet or exceed annual payments to cover all project costs. If savings don't materialize, the ESCO pays the difference, not the client. To ensure savings, the ESCO offers staff training and long-term maintenance services. Many types of operating improvements can be funded through the savings without injecting new capital into existing budgets. Three very essential parts of energy performance contracting are *performance guarantees*, *functional procurement*, and *financing*.[50] The basic principles of an energy performance contracting deal are presented in figure 5.

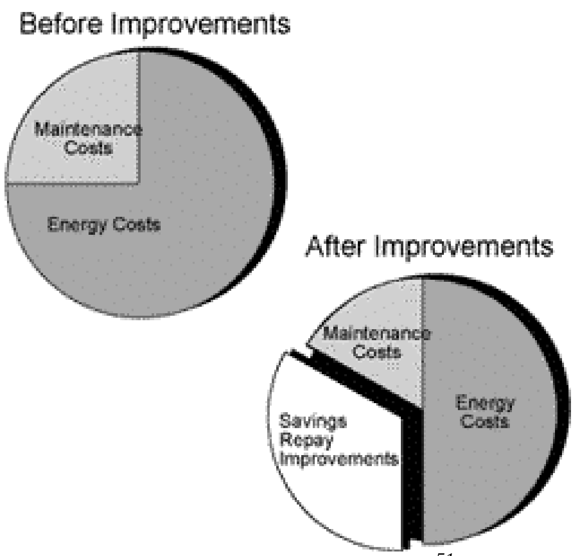

Figure 5 *Principles of energy performance contracting[51].*

[49] Delve & Wilkins (2002)
[50] http://www.energyservicescoalition.org, 2008-05-06
[51] Ibid

3.5.2 Performance Guarantees

What sets ESCOs apart from other firms that offer energy efficiency, like consulting firms and equipment contractors, is the concept of performance-based contracting. The ESCO that enters into an agreement guarantees the functions stated in the contract. The ESCO is thereby responsible for the economic risk of not meeting the function. When an ESCO undertakes a project, the company's compensation, and often the projects financing, are directly linked to the amount of energy that is actually saved. Typically, the comprehensive energy efficiency retrofits inherent in the projects require a large initial capital investment, and imply a relatively long payback period. The customer's debt payments are tied to the energy savings offered under the project, so that the customer pays for the capital improvement with the money that comes out of the difference between pre-installation and post-installation energy use. For this reason, ESCOs have led the effort to verify, rather than estimate, energy savings. Most performance-based energy efficiency projects include the maintenance of all or some portion of the new energy efficient equipment over the life of the contract. Therefore, during the life of the contract, the customer receives the benefit of reduced maintenance costs, in addition to reduced energy costs. As an additional service in most contracts, the ESCO provides any specialized training needed so that the customer's maintenance staff can take over at the end of the contract period.[52]

3.5.3 Functional Procurement

To make functional demands instead of asking for certain product specifications is the essence of functional procurement. It means that the procurer defines his or the organization’s needs instead of defining the product that intends to perform the function. Incorporating functional demands into the procurement process enhances the opportunities for the supplier to be creative. An important aspect of the functional procurement process is for the procuring part to correctly define its needs. Many types of building improvements utilize functional procurement, where an indoor climate is procured, as opposed to acquiring individual energy meters, temperature sensors, etc. The function “indoor climate” can include everything from new windows and wall insulation, to education and technical support. Within a building improvement project, dimensions such as temperature intervals and noise levels are defined. How the ESCO delivers these functions is not of importance as long as functions can be measured and verified. The overriding goal of functional procurement is to reduce operating costs and to improve the required functions.[53]

3.5.4 Financing

The project can be financed in different ways, but the most common are cash payments, bank loans, leasing, or third party financing. Cash payments or bank loans from credit institutes are common ways of financing investments in assets that are exploited during operations. Leasing implies that the receiver of the lease has the right to use the asset, according to a contract, during a fixed period of time for a certain fee. When the buyer does not have the necessary investment capital and cannot arrange for a bank loan, third party financing is an alternative. In this case, the

[52] http://www.energyservicescoalition.org, 2008-05-06
[53] http://www.epec.se, 2008-05-06

ESCO provides the capital by borrowing from a third-party, and then, in turn, lends the money to the buyer for a fee.[54] From the client's perspective, cash financing is the cheapest alternative, followed by bank loans, leasing, and finally third-party financing.

3.5.5 Benefits and Drawbacks of Energy Performance Contracting

By updating or replacing equipment that is old and obsolete with newer, more efficient technologies, higher-quality systems are achieved, fewer breakdowns are experienced, and maintenance is reduced. Energy performance contracting allows scarce resources that would be spent on energy bills to be used where they are needed the most. For governments, this means that limited budgets can be stretched further, putting taxpayers' money where it really counts. Energy efficiency projects can be tackled directly, even if no funds are available, as the project pays for itself. This means that improvements can still be afforded even when faced with budget cuts. Several clients that have signed an energy performance contracting deal see direct energy savings of 15 to 35 percent, and additionally reduce their long-term maintenance costs.[55]

In energy performance contracting projects, the ESCO typically has an advantage in terms of procurement and contracting knowledge, especially when the buying entity is a government institution. Therefore, the ESCO has the upper hand, resulting in more expensive services than necessary. The buying entity is often convinced of financing the project with the third-party alternative, which, as previously mentioned, is not the most favorable for the procuring entity. The municipality is advised to acquire support from consultants within the field of public procurement in order to compensate for the ESCO's upper hand position.[56]

[54] http://www.epec.se, 2008-05-06
[55] http://www.energyservicescoalition.org, 2008-05-06.
[56] Svensson (2007), p. 9

4 Local Governments in Sweden

This chapter aims to provide the reader with knowledge regarding the role of local governments and their responsibilities, as this is the context in which public street lighting is managed.

4.1 Organization and Responsibilities

The highest decision-making body in a local government is the main council, as elected by the citizens. Elections are held every four years at the same time as parliamentary (Riksdag) elections. The main council appoints a board and decides upon which other bodies and committees to establish. The board manages and coordinates the administration. This role gives the board a central function for supervision and influence over the various operations. The board is responsible for producing budget proposals and drawing up annual and interim financial reports, and is also otherwise responsible for financial administration. The main council handles important financial decisions relating to, for example, the budget, tax rates, fees and borrowing. Special legislation has given the local governments responsibility for important social functions, which are often compulsory tasks. The municipalities have a wide range of tasks to carry out, while the main focus of the county councils relates to health and medical care. The local governments may also conduct operations through other legal entities, such as limited companies, if there is no particular regulation in law governing how an operation should be run. [57]

4.2 Income and Costs

The majority of public sector services, including education, medical care, and care of the elderly, is provided by the local governments, and accounts for 75 percent of total municipal and county council costs. The local governments' use, excluding their companies, accounts for 70 percent of public expenditure and 20 percent of GDP. The activities are personnel-intensive, and the cost of personnel and procurement of operations (personnel) account for two-thirds of the overall costs.[58] 85 percent of total income comes from taxes, fees and other income.[59]

The local governments in Sweden have a constitutional right to levy taxes for carrying out their tasks. Income from taxation accounts for just over 70 percent of all funding. Each local government sets its own tax rate. The tax base is based on the residents' income, and there is no legal restriction on the size of the tax base. In 2006, the local government tax amounted to an average of 31.6 percent of residents' income in Sweden. The county councils accounted for 10.8 percent and municipalities for 20.8 percent. The local governments are also entitled to charge fees for particular activities, within certain limits. To further strengthen the financial situation of the local governments, and to ensure equality of circumstances between different local

[57] http://www.skl.se, 2008-04-03
[58] Ibid
[59] Swedish Assosiation of Local Authorities and Regions (2007), p. 13

governments, the State contributes to their revenues through general and targeted grants, as well as through a system of local government financial equalization. The state grants equate to 15 percent of total income.[60]

4.3 Financial Requirements imposed on the Local Governments

The overall goal of the financial management in the local governments is to maintain *sound financial management* in the operation, which entails using resources economically in the short and long term. Each local government has to set goals and guidelines for the operation that are of significance to sound economic management. These goals are to be expressed both as financial and operational goals, and are essential to the economic management. The annual financial report has to include an assessment of whether the goals have been achieved, and the auditors also have to assess goal achievement autonomously.[61]

Every year, local governments have to define a budget and a financial plan for the next three years (including the budget year). The *requirement for a balanced budget* has applied since 2000, and states that the budget should normally be set with income exceeding costs. If the council decides to introduce new expenditures during the current budget year, the decision must also contain details of how the expenditure is to be funded. If a deficit is reported for a particular financial year, the general rule is that the council, after looking into the balance requirement, must adopt an action plan for restoring the deficit after no more than three years. Accounting and reporting must be in line with generally accepted accounting principles, and every year the local governments must draw up an annual report, and at least one interim report, for examination by the main council. The annual report must contain an administration report, an income statement, a balance sheet, and a cash flow analysis. Control and inspection are carried out by auditors selected by the main council.[62]

The requirement of a balanced budget implies economizing on resources in two dimensions; in time and over time. In other words, the budget should be balanced with the activities undertaken by the local governments in the short run as well as in the long run. If the budget is overridden this year, the next year or next generation has to pay for that over-consumption. Therefore, positive results are needed to finance activities over time. Assets are depreciated to cover the cost of wear, and the annual depreciation is based on historical purchase price. At the same time, existing technology is often replaced by more advanced technology, which often comes at a higher cost. To upgrade or replace existing technology, surplus is needed to cover the difference between level of investment and depreciation. Otherwise, external capital needs to be raised, and consequently, further capital expenses are added to the operating account.[63]

[60] Swedish Assosiation of Local Authorities and Regions (2007), p. 13
[61] http://www.skl.se, 2008-04-03
[62] Ibid
[63] SKL (2005), p. 7

The local governments in Sweden have the right to make autonomous decisions on their borrowing without scrutiny or approval by the State. The local governments decide for themselves which products and markets are to be used to raise borrowing. The main council adopts guidelines and policies to limit operational risks. Borrowing is indirectly limited in that all costs associated with the debt must be included in the balanced budget. However, there is no direct volume limit restricting the borrowing of the local governments.[64]

4.4 Public Procurement

The EU provides certain regulations for public procurement in order to use taxpayers' money effectively and to support transparent and effective competition. The following procedures are regulated through the Swedish Public Procurement Act, defined by the Swedish Competition Authority.

When the procuring party has decided upon what it wants to procure, the product or service shall be described in a tender document. The description shall be based on objective criteria, and preferably refer to technical standards or specifications. The new directive's enumeration of criteria include, among other things, price, quality, esthetics, delivery, and environmental characteristics. The criteria present in the tender document must meet certain qualifications in order be approved. The description in the tender document allows for the suppliers competing for the contract to make comparative tenders to the procurer. The description is also of importance for the procurer to make an assessment of the most advantageous offer. The procurer must not describe the product or service in such a way that prohibits effective competition.[65]

The procuring entity must state the relative importance of each of the criteria in the tender document. This means that the procurer should, for example, state that price will be weighted at 80 percent, while quality will receive a weighting of 20 percent when deciding upon to whom the contract shall be awarded. If weighting the criteria is not possible, the procurer shall instead state the criteria in order of importance. The procuring entity shall take all incoming offers into account and accept that which, in accordance with the tender document, has the lowest price or is most economically advantageous. When the procurer decides upon accepting the offer with the lowest price, only the price is acknowledged. This must be clearly stated in the tender document. When the most economically advantageous offer is accepted, the procurer acknowledges other criteria in addition to price.[66]

4.5 Purchasing Policy

Government purchasing often serves political objectives. At the same time, the government must spend its financial resources as efficiently as possible. However, these objectives are not always complementary. For example, a political intent of

[64] SKL (2006), p. 7
[65] http://www.eu-upplysningen.se, 2008-04-25
[66] Ibid

primarily involving local firms in the tendering process in order to stimulate employment in their region may conflict with getting the best value for money by tendering among a larger number of firms. This shows that social and political objectives can often be in conflict with a rational spending of budgets, and thereby, purchasing decisions in governmental institutions such as municipalities cannot be made solely on economic grounds.[67]

A municipality is constrained by the central government's budget policies. In general, the money that is allocated to them in a certain year also needs to be spent in that year. It is in many cases difficult to build up financial reserves and shift these to the following year. This may have an adverse affect on purchasing savings. If a certain department is able to save money through smart purchasing, it is required to return this money at the end of the year to the local authorities. Thereby, clear incentives to save money through professional purchasing within a municipality are missing. Instead, a department will most likely concentrate on spending all available funds in order to not receive less the following year.[68] In addition, fixed budgets might also stop governmental institutions from taking advantages of quantity discounts and longer-term contracts.[69]

Another complicating factor is that investments and exploitation, or operation, are generally financed from different budgets. The result is that investment decisions are often made without a careful balancing of costs during the exploitation stage. This prevents the adoption of a purchasing approach based on total cost of ownership.[70]

Governmental institutions are publically responsible for how they spend their money. As government personnel are subject to public scrutiny, they tend to be risk averse and conservative in their purchasing behavior.[71]

[67] Van Weele (2005), p. 341
[68] Ibid
[69] Burt (2003), p. 597
[70] Van Weele (2005), p. 341
[71] Burt (2003), p. 597

5 Public Street Lighting

This chapter presents the role and technology of public street lighting, which consists of various parts that can be replaced by more energy efficient solutions. Some of the vocabulary used in this, and later chapters, may be slightly difficult for the inexperienced reader to comprehend. Therefore, a glossary containing the most commonly used terminology with respect to street lighting is provided in appendix 6. The chapter ends with recommendations to sources of more detailed information on street lighting.

5.1 Purpose of Street Lighting

Road and street lighting have three main purposes. Firstly, street lighting assures that motorists, bikers, cyclists, and drivers of other vehicles can travel safely. It facilitates for pedestrians to discover risks, orientate themselves, recognize other pedestrians, and infuses a feeling of security. Lastly, street lighting promotes the shape of the surroundings by night.[72]

5.2 Lamps

This section provides a basic introduction to lamps, including how they work and general characteristics. There are three main types of lamps used in public lighting – discharge lamps, LEDs, and induction lamps. An understanding of how lamps work can assist in choosing suitable lamp technologies.

5.2.1 Discharge Lamps

Discharge lamps are the most common type of lamps used for street lighting in Sweden, including mercury vapor, high-pressure sodium (HPS), metal halide, and low-pressure sodium, of which the first three constitute high intensity discharge lamps. HPS lamps are very efficient and exist in a wide range of wattages. Mercury vapor lamps are the most common lamps in Sweden, and are cheap, tough, and reliable. However, they have a low efficacy, rapid lumen depreciation, and use a high quantity of mercury. The main drawback is the poor color rendering index. Metal halide lamps have a better performance than mercury vapor lamps, excellent color rendition, but the lamp life is short compare to HPS lamps.[73]

5.2.2 LED (Light Emitting Diode)

LEDs are most commonly used in traffic lighting applications. Unlike HPS lamps, LEDs provide significantly improved color-rendering characteristics, introducing the opportunity to reduce light levels due to vastly improved uniformity. LEDs offer significant municipal advantages, including the reduction of capital investments in replacement part inventories, as well as reduced down time and service interruptions due to less component failures.[74]

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[72] Commission Inernationale de l'Eclairage (1995)
[73] http://www.iclei.org, 2008-04-02
[74] Grow (2008), p. 7

In many applications, LEDs are expensive compared with other lamps when measured by metrics such as "dollars-per-lumen". LED manufacturers continue to work towards reducing their production costs, while at the same time increasing the light output of their devices. However, the high initial cost of LED-based systems is offset by lower energy consumption, lower maintenance costs, and other factors.[75]

In 2005, Ann Arbor established a moratorium on new street lighting aimed at helping to keep costs under control. As part of this cost cutting initiative, the city began trialing LEDs for general lighting purposes. LEDs reduce lighting energy requirements by 50% or more, but their greatest benefit is that they last much longer than conventional bulbs, reducing labor and maintenance costs. In Ann Arbor, this will translate to annual CO_2 reductions of 2,200 tonnes, and annual savings of SEK 700 per fixture.[76]

5.2.3 Induction Lamps

The gas in an induction lamp is ionized by an induced electromagnetic field, and not by an electrical discharge, as in discharge lamps. Therefore the lamp life is long, which reduces maintenance costs and inventory. The induction lamp has good color rendering, usually over 80, and appearance. It also restarts instantly and frequent switching does not adversely affect the lamp life. On the downside are higher initial costs, which may deter purchasers who do not understand the rapid payback from lower operating costs. Induction lamps are not suitable for use with dimmers and similar electronic control devices. [77]

5.2.4 Lamp Characteristics

Lumen depreciation measures how much the light output of the lamp diminishes over its useful life. Lumen depreciation is important when considering the maintenance factor of a luminaire and the lamp. Figure 8 below shows the typical lumen depreciation curves for common types of lamps.[78]

[75] http://www.ledsmagazine.com, 2008-04-04
[76] http://www.nycclimatesummit.com, 2008-04-02.
[77] http://www.gelighting.com, 2008-04-04
[78] http://www.iclei.org, 2008-04-02.

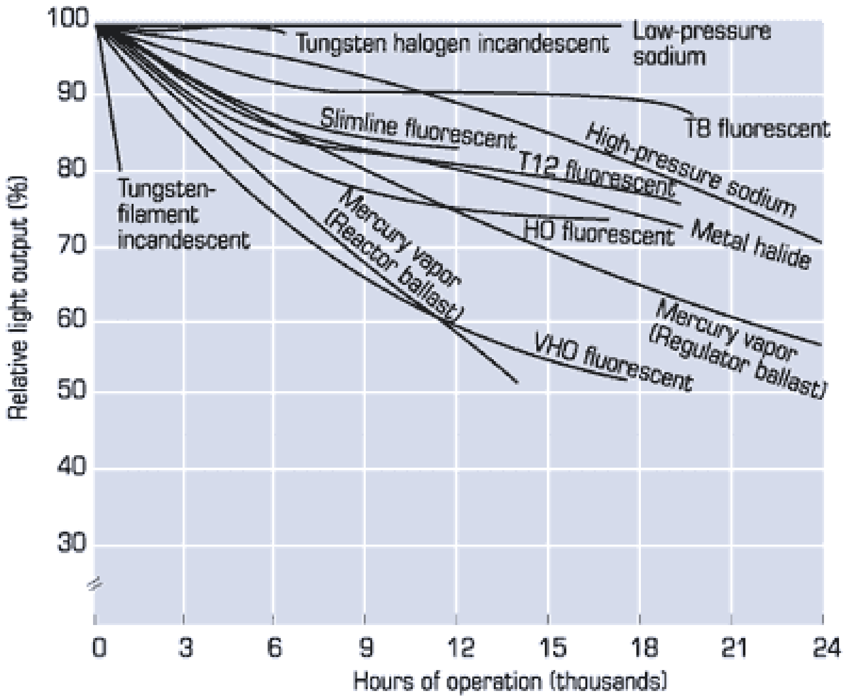


***Figure 6** Lumen depreciation curves*[79]

The unit of *efficacy* corresponds to Lumens per watt. Efficacy measures how efficient the lamp converts electrical energy into light. A comparison between lamps should take into account the power consumed by the ballast.[80]

Light color is measured by both the lamp's "temperature" and the color rendition index (CRI) of the resulting light. The CRI measures how close a color is rendered by the lamp to the "real" color, on a scale from 1 to 100. A CRI of 100 means that all colors are correctly rendered. The lamp temperature measures the color temperature of the light from the lamp, and is measured in degrees Kelvin. Metal halide lamps, with very good light quality, have lamp temperatures of 3000 to 4000 K. When specifying the color of light from their lamps, some manufacturers use the CRI and others use the lamp temperature.[81]

Lamp temperature performance measures the ability of the lamp to perform and to produce its rated output at a given temperature. Some lamps may produce less than their rated output if temperatures are too cold or too hot.[82]

[79] http://www.iclei.org, 2008-04-02
[80] Ibid
[81] Ibid
[82] Ibid

Lamp life measures the life of the lamp, usually expressed as the number of hours of operation by which a percentage of a group of lamps has failed. The specified percentage may vary from manufacturer to manufacturer, making comparisons difficult.[83]

Lamp reliability and toughness is a subjective assessment of the lamp's ability to deal with adverse conditions, such as over voltage, under voltage, spikes, transients, vibration, and rough handling. Its electrical reliability and toughness depends to a large extent on the ballast used and the degree of protection the ballast offers the lamp.[84] Table 3 provides a comparison of some lamp characteristics.

***Table 3** Lamp characteristics*

Lamp type	Efficacy (lumen/watt)	Typical lumen depreciation before replacement	Color Rendering index, light color	Lamp life (hours)	Reliability and toughness in public lights
Mercury vapor	40 to 50	30 to 40%	40-60	14,000 to 20,000	Very good
High pressure sodium	70 to 85	20 to 30%	Up to 40, orange	24,000 to 40,000	Very good
Metal halide	70 to 80	20 to 25%	80-90	9,000 to 15,000	Fair
T5 fluorescent	90 to 105	10%	80-85	20,000	Good
Compact fluorescent	70 to 80	10 to 20%	80-85	10,000 to 12,000	Fair
LED (white)	10 to 20	N/A	70	80,000 to 100,000	Fair
Induction	80	30 to 35%	80	60,000 to 80,000	Good, largely unproven

5.3 Ballasts

Discharge lamps and LEDs cannot be connected directly to the mains and they sometimes need a lamp starting aid. Therefore, lamp control gear is needed. The control gear has two functions. It ignites and controls the lamp by supplying the right lamp voltage and limiting the electric current. Control gear conventionally consists of three parts: a ballast (coil), a capacitor and an igniter. The control gear is commonly referred to as ballast. Alternatively, electronic gear, also known as electronic ballast, is used in some cases. The ballast lifetime depends on service hours. Normally, magnetic ballasts last as long as the luminaires if they are placed inside the luminaire.

[83] http://www.iclei.org, 2008-04-02.
[84] Ibid

The lifetime of a electronic ballasts is 40.000 to 60.000 hours, which constitutes 10 to 15 years, according to manufacturers. There is a new trend to introduce electronic ballasts for street lighting that offer more power control and dimming. Also, voltage stabilizers to control the line voltage, and thus lamp power, are sold for this purpose. Each defined lamp type and wattage needs its own ballast. Consequently, once the ballast is installed in the luminaire, it is very difficult to change lamp power or type.[85]

5.4 Luminaires

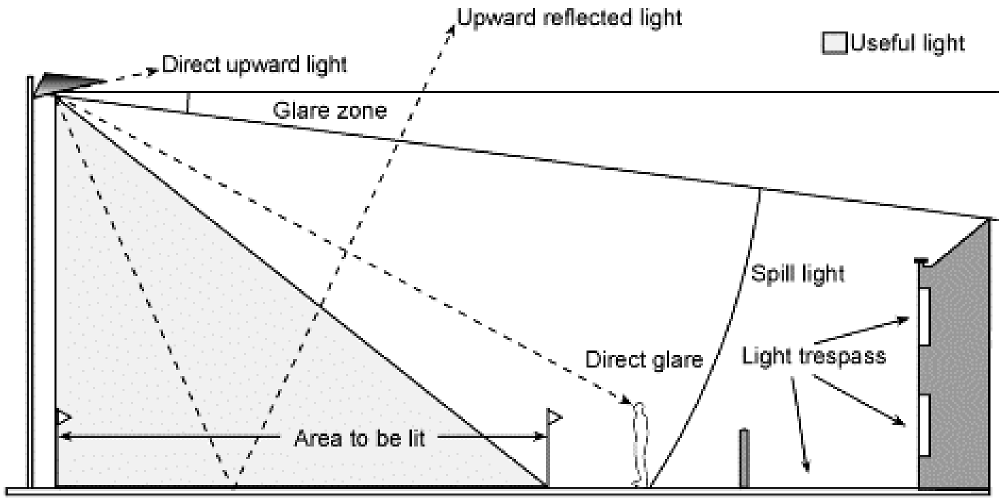
The luminaire is a significant factor in determining both the cost and performance of a streetlight. This section provides a basic introduction to luminaires, including the characteristics by which they can be assessed, energy use, performance and appearance, lighting design, and luminaire classifications.

5.4.1 Luminaire Characteristics

The light output performance determines how effectively the luminaire transfers the light output from the lamp into useful roadway lighting, and it is defined by three factors: the efficiency of the luminaire in directing the light from the lamp onto the road; the amount of light trapped in the luminaire housing; and the amount of light that comes out of the lamp above a horizontal plane.[86]

Light pollution is an unwanted consequence of outdoor lighting and includes such effects as sky glow, light trespass, and glare. To limit the light pollution, luminaires need to be selected with great understanding of where light is needed and not wanted. An illustration of both useful light and the components of light pollution are illustrated in figure 9. [87]

[85] Van, Tichelen (2007), p 81
[86] Ibid
[87] Ibid



Light pollution is often caused by the way light is emitted from lighting equipment. Choosing proper equipment and carefully mounting and aiming it can make a significant difference.

Figure 7 *Example of useful light and light pollution from a typical pole mounted outdoor luminaire.*

5.4.2 Achieving Efficient Luminaires

Given the same lamp, pole spacing will be maximized with a luminaire that has good light output performance. The greater the distance between poles, the less energy used, and consequently significant financial savings can be achieved. An engineered luminaire provides the most even light distribution across the road for the greatest distance. There is, however, a trade-off between the throw of a luminaire and its upward light ratio. Aeroscreen diffusers, typically used on higher power luminaires, stop any light from going upwards but also limit the useful sideways throw of the lamp unless mounted on a very high pole. Aeroscreen luminaires tend to require closer pole spacing, which increases the energy used per linear meter of road.

The appearances of the luminaire and the pole have become increasingly important in recent years. As a result, new developments heavily favor decorative luminaires. These luminaires are more expensive than standard luminaires, and because of their poor light output performance, have to be installed at closer pole spacing. Thus, as well as requiring more energy, the use of these luminaires comes at increased capital and operational costs per linear meter of street compared to a standard luminaire. Municipalities and developers should be aware that not only are most decorative luminaires more expensive to own and operate, they also use more energy and have a larger environmental footprint per linear meter of street than standard luminaires.[88]

[88] http://www.iclei.org, 2008-04-02.

5.5 A Managed Streetlight System

The new international standard for road lighting[89] and the new European standard[90], as well as VGU, allow a reduction in luminance during non peak-hour traffic, usually from 10 pm to 5 am. These new standards are also supported by a study, which concludes that a luminance reduction by up to 50% has no negative effect on the visibility as long as the uniformity is not reduced[91].

Today’s technology is not only able to adjust luminance levels in accordance to traffic and weather conditions, but also to detect and report failures of lighting circuits and even single lamps. A *managed streetlight system* is a system that automatically reacts to external parameters like traffic density, remaining daylight level, road constructions, accidents, or weather circumstances. The system consists of three main parts – *luminaire controller*, *segment controller*, and a *central management system*.[92]

First of all, a luminaire equipped with a dimmable lamp is an important part of the system. The basic set-up is a lamp and smart dimmable ballast in combination with a controller for this ballast. The luminaire controller is the component that forms the link between the dynamic lighting system and the lamp.[93]

The luminaires are connected to a power supply cabinet and communicate with the segment controller. This basic infrastructure part consists of an intelligent controller that handles various functions like scheduling, control, data logging, and alarm handling per segment, as well as the WLAN communications to the overall management system. The segment controller is the main part in the local lighting installation and should be based on open technology, so that it is possible to easily modify or expand on it in the future.[94]

The central management system is used to control the segments and manage the data coming from the segment controllers. It also keeps track of where the segment controllers are and informs the user of when to replace the bulbs. The system remains functioning even if the central management fails, because it consists of a network of decentralized intelligence in the segment controller. The luminaire controllers check the lighting, either by using information from ballasts or by using extern signals. The remaining parts of the system can keep functioning autonomously, even if one of the components, or a part of the system, fails.[95]

The city of Oslo, in Norway, has a managed streetlight system, which is the first large-scale implementation of its kind in street lighting applications. It is expected to reduce energy usage by over 50 percent, improve roadway safety, and save money by

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89 Commission Internationale de l’Eclairage (1995)
90 European Committee for Standardization
91 Hogema (1998)
92 Walraven (2006), p. 10
93 Ibid, p. 11
94 Ibid, p. 12
95 Walraven (2006), pp. 14-15

minimizing maintenance costs. Oslo is replacing older, inefficient mechanical ballasts in the City's 55,000 streetlights with "smart" electronic ballasts. Data from the streetlights will be collected by approximately 1,000 segment controllers, which manage the streetlights and communicate with the city of Oslo's monitoring center. Internet servers will log and report energy use, collect information from traffic and weather sensors, and calculate the availability of natural light from the sun and the moon. This data is used to automatically dim streetlights based on the season, local weather, and traffic density. This system has the capacity to control and save electricity with even the newer energy efficient LED lamps. The technology provides total control of the streetlight system, will lower energy, operations, and maintenance costs, while ensuring proper roadway illumination required for public safety. As is the case with all energy management systems that leverage a distributed control network, the city of Oslo is able to calculate a return on investment that includes energy and operational savings. In Oslo's case, energy and maintenance savings that will be achieved will pay for the new system within five years.[96]

5.6 Street Lighting in Further Detail

For a more detailed description of technical quality of light, the reader is advised to study *prEN 13201 Road Lighting*[97], or the Swedish National Road Association's recommendations for the design of roads and streets, *VGU*[98] A summarized compilation of known legislation with respect to street lighting can be found at the European Commission's web portal, *Intelligent Road and Street lighting in Europe (E-street)*[99].

[96] Grow, pp. 7-8.
[97] CEN TC 169 226 JWG (2001)
[98] Vägverket (2004)
[99] http://www.e-streetlight.com

6 Drivers To Investment in Lighting Technology

This chapter aims at highlighting drivers to invest in efficient streetlight technology. The drivers are divided into three categories – commercial drivers, professional drivers, and political drivers.

6.1 Commercial Drivers

This subchapter attends the pure economic figures – investment costs and monetary savings – related to the investment in a managed street lighting system.

6.1.1 Cost of Investment

An investment in new streetlight technology can include lamp retrofits, where a 125 W mercury vapor lamp is replaced with the same lamp. Another quite common investment is to change the luminaires, going from 125 W mercury vapor luminaires to either 50 or 70 W high-pressure sodium luminaires. A third alternative is a full-scale approach where not only the luminaires and lamps are changed, but also the central managed system, the supply cabinets, and the dimmable electronic ballasts are installed. In addition, some lamps might even be replaced with LEDs where suitable.

A rough estimate of the costs of implementing the full-scale alternative would include new luminaires pre-installed with the new smart electronic ballasts and lamp system controllers. Simultaneously, all mercury vapor lamps should be replaced with efficient high intensity discharge lamps. Next to be installed are the segment controllers, where one segment controller is required for every 60-70 streetlights[100]. This may vary depending on the particular architecture of each streetlight system. Once smart electronic ballasts, HID lamps, and segment controllers are installed, it is possible to control streetlights from a central command post, where the central management system is installed. The cost of each item is found in table 4 below.

Table 4 *Cost of components in a managed streetlight system*[101]

Managed Street Lighting Component	Unit Cost (SEK)
Luminaire	1,200
Electronic ballast	900
Lamp controller	1,100
HID lamp	50
Segment controller	10,000
Central management system	50,000

6.1.2 Savings Potential

Up until now, LEDs have rarely been used in street lighting because of the high prices and lower efficacy, but technology is changing.[102] Nevertheless, out of simplicity we

[100] Telephone interview with Johansson, 2008-04-15
[101] Telephone interview with Johansson, Jerleke, and Niklasson, 2008-04-15

are using high-pressure sodium as an example. Presently, approximately 50 percent of the streetlights in Sweden are lit using energy in-efficient mercury vapor lamps[103], consuming a relatively large amount of electricity during their lifetime, and with limited efficiency. By shifting to high-pressure sodium or metal halide lamps, efficiency improvement in the lamp itself could be as high as 40%. This could reduce total energy use for street lighting in Sweden by approximately 15%. Shifting all lamps, also the newer types, to the most efficient lamps could reduce energy use by another 5-10%.[104] The total energy saving potential in replacing all lamps is therefore approximately 20%.

The development in lamp size and the characteristics in optical design mean that the efficiency of modern luminaires can be 25-30% higher than those based on optical systems for old elliptical lamps. If all streetlight luminaires were to be replaced with the latest technology, the energy saving potential is estimated to 15%. The savings can only be accomplished in combination with new lamps.[105]

With a managed street lighting system and the smart electronic ballast, each streetlight can be individually dimmed so that the electricity use is lowered by about 50 percent, without any negative effect on the visibility, as concluded earlier. On average in southern Sweden, the streetlights can be dimmed between 8 pm and 6.30 am. Due to heavy traffic, it should be fully lit from 6.30 to 8.30 am and from 4.30 to 8 pm, and switched off during the day. This translates to a total savings of 34 percent[106], not including savings from the new luminaires and lamps.

Additional savings can be realized in operation and maintenance of the streetlights. The saving benefits of high-pressure sodium lamps will be further enhanced under a managed streetlight system, as the lamp life is extended by 50 percent, translating to 24,000 hours, or six years, instead of four years. Around ten lamps can be replaced per hour. Apart from replacing lamps, road crews usually check for lamp failures three to five times a year in Sweden. With the managed lighting system this can easily be reduced to every other year, which has positive effects on costs. Each inspection, or lamp replacement, involves one person driving a sky lift. This costs 400 plus 900 SEK per hour for the labor cost and the sky lift respectively. On average, 50 luminaires can be inspected per hour.

[102] Van, Tichelen (2007), p. 81
[103] Telephone interview with Frantzell, 2008-03-12
[104] Grow, p. 6
[105] http://www.e-streetlight.com, 2008-03-04
[106] Fully lit 5 hours and 50 percent reduction due to dimming for 10,5 hours

6.1.3 Example Savings – 10,000 Managed Streetlights

Table 5 *Investment cost managed system, 10,000 streetlights*

Managed Street Lighting Component	Unit cost (SEK)	Total (SEK)
Central management system	50,000	50,000
150 Segment controllers	10,000	1,500,000
10,000 Luminaires	1,200	12,000,000
10,000 Smart electronic ballasts	900	9,000,000
10,000 Lamp system controllers	1,100	11,000,000
10,000 HID lamps	50	500,000
Total cost for a 10,000 streetlight system		**33,550,000**

Table 5 presents the cost involved in implementing a managed streetlight system for an installation of 10,000 streetlights. The average streetlight in Sweden uses 433 kWh annually, and with 10,000 streetlights this equates to 4.3 million kWh. Assuming a lamp savings potential of 20 percent, this would save nearly 1 million kWh annually, or SEK 1 million at a price of 1 SEK per kWh. In addition, 15 percent in energy use is saved due to the new efficient luminaires, which constitutes a reduction of 0.65 million kWh and SEK 650,000 annually. The dimming function reduces energy consumption by 34 percent, which translates to roughly 1.5 million kWh. Each saving opportunity – lamp, luminaire and the dimming function – is presented in table 6 below.

Table 6 *Saving opportunities for individual components*

Saving opportunity	Annual Energy saved (kWh)	Annual SEK saved
Lamps	866,000	866,000
Luminaire	650,000	650,000
Dimming	1,470,000	1,470,000
TOTAL	**2,986,000**	**2,986,000**

As seen in the table above, the full-scale approach, including the lamp savings and the reduction in energy consumption due to dimming, translates to total energy savings of 69 percent, which equals almost 3 million kWh and 3 million SEK in annual savings, assuming an energy price of 1 SEK/kWh.

Without the managed system, the annual labor cost (SEK) of replacing lamps is SEK

$$4{,}000/16{,}000 \times 10{,}000/10 \times (400 + 900) = 325{,}000$$

This does not include the replacement of lamps that fail before their lamp life has expired. With the dimming function, which extends the lamp life by 50 percent, the cost of replacing lamps would be reduced to SEK 162,500. Assuming that a municipal inspects all lamps four times a year, the cost would amount to SEK

$$4 \times {}^{10,000}\!/_{50} \times (400 + 900) = 1{,}040{,}000$$

With a managed street lighting system, inspections are required only each second year instead of four times a year, which means that the annual cost can be reduced to SEK 130,000.

The savings obtained through energy reduction and labor costs associated with the lamp replacement and the inspections, results in a total system saving of SEK 4,058,500. The payback period of a SEK 33.55 million upgrade for a municipality with 10,000 streetlights would be approximately 8 years.

In the calculations above, relatively conservative assumptions have been made. First of all, and most importantly, the above calculation is not dynamic. In other words, all costs are constant, including the cost of energy. Analysts are forecasting a continuous increase in the price of electricity over the next 10 years.[107] This means that the investment becomes far more interesting, as the cost of electricity is the major part of total costs. No LEDs have been included in the investment calculation, and the dimming at night does not go below 50 percent of full effect, even though it is possible to dim the streetlights to as low as 35 percent[108]. In addition, benefits such as the reduction in crime rate also reduce costs but are very difficult to measure.

6.2 Professional Drivers

In addition to the economic incentives presented above, the following drivers support an investment in new streetlight technology.

- **Common technical specifications.** The partners of the European Commission’s E-street project are currently developing specifications for managed streetlight solutions in order to standardize the customers’ demand, thereby opening up a larger market for the manufacturers and vendors. Such standards will be easy to integrate into standard contracts, either for new installations, retrofitting, or maintenance.
- **Improved maintenance.** The valuable information given by the system makes it possible to plan and organize the maintenance tasks cost effectively. In the Nordic countries, many installers are starting to use handheld computers, as well as GPS, in their daily work, which facilitate more time and cost efficient operations.
- **Information about the electricity supply quality.** Today, a lot of street lighting installations have poor electricity supply and old grid systems. Detection of voltage and other electricity performance criteria will make it

[107] Echelon Corporation (2007), p. 3
[108] Telephone interview with Niklasson, 2008-04-15

necessary to improve the installations in the future, thereby opening up for new technology.

- **Metering.** A high percentage of all European streetlights are not directly metered, implying that a lot of clients do not know their exact consumption. New regulations forcing all trade of energy to be metered will stimulate the introduction of two-way communication into the streetlight switch cabinets/sub station power supply. When the two-way communication is established, marginal costs for introducing managed street lighting systems are lowered.[109]

6.3 Political Drivers

- **Symbolic value of the municipality to be the first.** The political focus on energy efficiency is important, because of the symbolic effect of, for example, dimming the light by night. Thus, the municipality can show the public that it is possible to significantly reduce their electricity use by relatively simple means. It also has a positive effect on the environment as less electricity is consumed.
- **Safety and crime prevention.** According to a Finnish meta analysis, the introduction of street lighting decreases fatal accidents by 65 percent, reduces personal injuries by 30 percent, and decreases property accidents by 15 percent[110]. In addition, empirical findings from the Oslo project exemplify how crime can be reduced. The main bar street is equipped with powerful streetlights that are set on full power as bars are closing, and has contributed to a lower level of crime. During other hours, the streetlights can then be dimmed to provide sufficient visibility.
- **Public service.** Today, the only way to detect a failed streetlight is by reports from the public, or by visual inspection of each street or road. When introducing a managed streetlight system, the municipality will immediately detect a failure, and as it will be known in advance, a replacement may be planned respectively. This will lead to shortened response times for changing lamps, increasing the overall level of light in the street during peak hours. The municipality is able to inform the public about the replacement of the lamps in their street.
- **Eco-design directive.** The eco-design directive will pay more focus to life cycle cost analysis, which will increase the competitiveness for energy efficiency solutions, and will thereby favor managed street lighting solutions. The plan for introducing new directives also includes street lighting for the near future.[111]

[109] http://www.e-streetlight.com, 2008-03-14
[110] Nygårdhs (2006), p. 7 and Commission Internationale de l'Eclairage (1992)
[111] http://www.e-streetlight.com, 2008-03-14

7 Identified Barriers

In the following chapter, the empirical information is analyzed and translated into a set of barriers hindering the realization of energy efficiency investments. The barriers are defined and discussed in terms of their origins and consequences.

7.1 Short-sighted Investment Horizon

From a theoretical viewpoint, public decision-making incorporates political, commercial, and professional judgments, and should collectively account for democracy, efficiency, and professional assessments.[112] Gathered from the interviews conducted in our case study, political reasoning has shown a tendency to overshadow the other two means of reasoning. By this we mean that the prioritized investments in municipalities are investments that are the easiest to advocate, i.e. investments with quick and highly visible results, towards the local citizens. For instance, one politician stated, “The reductions in energy consumption obtained by an investment in efficient street lighting technology are not visible to the local citizen. I would rather prioritize the sanitation of large public areas, as this is something that directly affects the citizens and is appreciated.”

The requirement of a short payback time is a dominating criterion within all the municipal levels encountered. Both politicians and municipal officers have generally expressed concern towards investments with a payback time of more than three years. Politicians seem to be the main enforcers of this short investment horizon, with the likely objective of wanting the results of their actions to be apparent within their length of office in order to maximize votes. One politician claimed that investments are prioritized on the basis of a short payback time or, alternatively, large effects. However, it is questionable whether municipalities have the proper tools to determine these “large effects”. An investment in efficient street lighting technology would adhere to this category, with positive long-term effects on the budget, environment, as well as the level of local security. These affects are either not apparent, or they are cast aside in favor of smaller projects with more immediate results.

As the balanced budget requirement states, the budget must not fall below zero any given year. This means that all unplanned investments should collectively show a neutral or, more favorably, a positive result as of year one. However, an exception is made if a detailed plan is developed for how to cover the loss over a three-year period. From what we have gathered, this available option is not utilized. For example, in two of the municipalities, objections were made towards the presented investment, as it did not show a positive result as of year one. We therefore believe that the requirement of a balanced budget is interpreted in a way that fosters shortsighted behavior, and therefore undermines investments that will eventually lead to large savings.

[112] Mattisson (2000), pp. 131-141.

As Mattisson[113] argues, one factor that might hamper the innovative climate in a municipality is that all actions are fully subjected to the insight of the public, creating a fear of being accountable for wrongful decisions. This was something that we identified through interviews with the heads of the technical administration. One such person claimed, “I cannot afford to make mistakes regarding large investments in new technology. Larger municipalities should pave the way in proving that the technology really works.”

7.2 Technology Ignorance

From what we have learned through interviews with operating technicians and traffic engineers, those working closest to the lighting technology within the municipalities, a sufficient technical knowledge about the municipality’s own installed base of luminaires and lamps exists. Some of them are also aware of energy saving opportunities such as the lowering of voltage during certain hours. Nevertheless, very few are aware of managed street lighting systems, where proven and reliable technologies combined with different IT solutions create a synergetic lighting system that allows for much greater energy saving.

From what we have gathered, a general skepticism pervades the technical level regarding new street lighting technology, its profitability, and how this technology can be integrated with the current installed base. According to Guillet de Monthoux[114], this can be categorized as both application and functional uncertainty. Many technicians have expressed doubts as to whether the new technology will function properly, and how fast this technology will be rendered obsolete through technical innovation. Together with a lack of information regarding the best available technology and its long-term financial and economic impact, the technicians are unaware of the existing incentives to invest in new street lighting technology.

The consequence of this is that a slow technological progression prevails in municipalities as they refrain from investing in new technology. For every investment opportunity that is bypassed, savings are lost due to rising energy prices, which further decreases available funds for future investments.

7.3 Lack of Investment Capital

A lack of sufficient investment capital to cover an investment of this magnitude is a barrier that we have identified on the technical level. Several of the operating technicians interviewed claim that it is practically impossible to obtain more funds than what has already been allocated to the investment budget. In addition, an unproportional amount of capital is distributed to the operating budget relative to the investment budget, leading to maintenance being prioritized before investments.

What is interesting is that the inability to obtain further investment capital is refuted on the political level, where it has been clearly stated that additional funds can always

[113] Mattisson (2000), pp. 131-141.
[114] Guillet de Monthoux (1975)

be obtained as long as the investment is financially sound. This suggests that there is a communicational obstruction between the two levels, consisting of an inability to internally market the benefits and economic potential of the investment towards the politicians. However, there is, as we see it, another important factor that practically makes this very difficult within municipalities.

The problem is that the investment budget and the operating budget are seen as two separate entities, as Van Weele[115] argues. Restrictions are placed on the investment budget because additional costs of capital are not preferred. This is due to the general opinion, gathered from all three municipal levels, that, in order to maintain a balanced budget, an increase in capital costs must be offset by relocating capital from another department. However, what is lacking is an understanding of the relationship between the two budgets. An investment that increases the quality of the street lighting installations generates savings in the operating budget in the form of decreased energy usage and a lesser need of maintenance. These savings may well more than cover the increased cost of capital. Municipalities do not seem to have realized how best available technology could lower energy costs, and neither do they seem to fully acknowledge increasing fraction of the operating budget that energy use accounts for. What is therefore needed is an investment perspective that incorporates all the financial consequences, both costs and savings, of an investment over time.

An additional consequence of the operating budget being unproportionally large in relation to the investment budget is that maintenance is prioritized before investments, leading to a very slow investment rate. For example, in Kristianstad, an average of 600 streetlights are replaced annually, implying an investment rate of 40 years. This is well beyond the normal depreciation life of 20 to 25 years. More importantly, undertaking sufficient maintenance is limited by rising energy prices, which are consuming a larger part of the operating budget each year. By not investing to minimize energy consumption, a large maintenance debt is created that accumulates as investments are postponed. There is a risk that the maintenance debt increases at too great of a pace, creating capital destruction as the assets deteriorate, and an inability for the municipality to live up to the requirement of sound financial management.

7.4 Insufficient Procurement Competence

Both technicians and heads of the technical administration have described public procurement as a very complicated procedure. There is a general uncertainty as to what specifications to demand when procuring new technology; certainly in this case where information regarding best available technology is lacking. We believe that this uncertainty drives the responsible procurers towards repeatedly purchasing the same technology, and to a large extent basing these purchases on the lowest available acquisition price.

[115] Van Weele (2005), p. 341

The Swedish Public Procurement Act allows for purchases to be made based on the lowest price or the most economically advantageous. The latter incorporates additional factors, such as quality, performance, and aesthetics. Although these additional factors are considered, our research shows that acquisition price is weighted the heaviest. The initial purchase price is a very objective criterion, and the procurers minimize the risk of being held accountable for inaccurate assessments during the procurement process by predominantly basing their decisions on this objective measure. There is no doubt that the procurer’s intentions are good when acquiring products with the lowest purchase price, but in the case of street lighting, this purchasing strategy is fundamentally wrong as the acquisition price is a minor part of the total costs over its lifetime. The intent of being objective is understandable, but nevertheless, taxpayers’ money is spent extremely unwisely, and the load on the environment is unnecessarily high.

None of the five municipalities encountered have incorporated tools into the procurement process that aid them in determining the costs of the procured equipment over time. Since there is no such tool for comparing energy and maintenance costs, which constitute a majority of the total costs incurred over the equipment’s lifetime, the most efficient technology is often overlooked in purchasing decisions.

8 Solutions to Barriers

In this chapter, strategies aiming at overcoming the previously identified barriers are suggested. It is important to stress that all recommendations and suggested strategies have one common goal – to speed up the elimination of energy inefficiencies by removing barriers.

8.1 Life Cycle Value

As mentioned earlier, the lack of investment capital is a barrier that was identified on the technical level within the municipalities. The politicians, however, refuted that this be an obstacle in pursuing investments of this nature, claiming that additional funds can be obtained if only the investment shows profitability. We therefore have confidence in the existence of excess investment capital within municipalities. However, in order to obtain this capital, the municipal officers need to be able to properly market the positive implications of the investment, showing its economic potential, and more importantly, how the additional capital costs associated with the investment will be counterbalanced.

In order to properly market the potential and economic impact of an investment in energy efficient lighting technology, the municipal officers closest to the technology must possess the required competence as well as necessary tools. First of all, in our view, it is imperative that the municipal officer presenting the investment grounds employs a life cycle value perspective. This implies that that all cost drivers beyond the acquisition price during the lifetime of the investment, including operating and maintenance costs, must be taken into account. However, in order to accentuate the savings potential associated with the investment, life cycle costs must be judged against the non-investment alternative, or in other words, the costs of maintaining and operating the current installations. By obtaining the difference between these two alternatives, the life cycle value of the investment becomes apparent. The life cycle value is equivalent to the money that is wasted by choosing not to invest. In addition, the value, in terms of annual savings obtained through the investment, presents a means by which to fund the additional capital costs without having to relocate capital from other areas of the municipality.

We have developed a life cycle value tool, as seen in Appendices 1-5, that can be of use for municipal officers in internally marketing the benefits of an investment in energy efficient street lighting technology towards local politicians. The tool enables the municipal officers to present the proper incentives for why additional capital should be allocated towards this investment, as well as why the investment horizon should be prolonged. The figures are based on information acquired through interviews with representatives from energy service companies, lighting equipment manufacturers, and the European Commission’s E-street project, and is exemplified with the five municipalities. The tool presents investment costs and the difference in operating and maintenance costs before and after the investment. The latter corresponds to the savings in the operating budget generated through decreased energy consumption and need for service and maintenance. The annual profitability, with respect to capital costs, and the accumulated life cycle savings are also presented. Lastly, in favor of political goals, the reduced energy consumption through the more energy efficient technology is translated to annual reductions in CO_2 emissions. This will provide politicians with additional support when promoting the logic behind such an investment towards to municipal citizens.

Figure 8 presents a graphic illustration of the economic impact of the investment on the future cash flows. Most importantly, figure 8 shows the relationship between savings and capital costs generated by the investment. During the interviews with the municipal politicians, both the tool and graphic illustration above were presented, and we were met by positive reactions on the whole. What is interesting to notice, is that as the focus of our conversations shifted from that of costs to savings and profitability, the strict requirement of a payback time of less than three years lessened. Yet some skepticism towards the fulfillment of these savings over time was expressed. An interesting way of dealing with this skepticism is through the use of performance guarantees, which will be discussed further on.

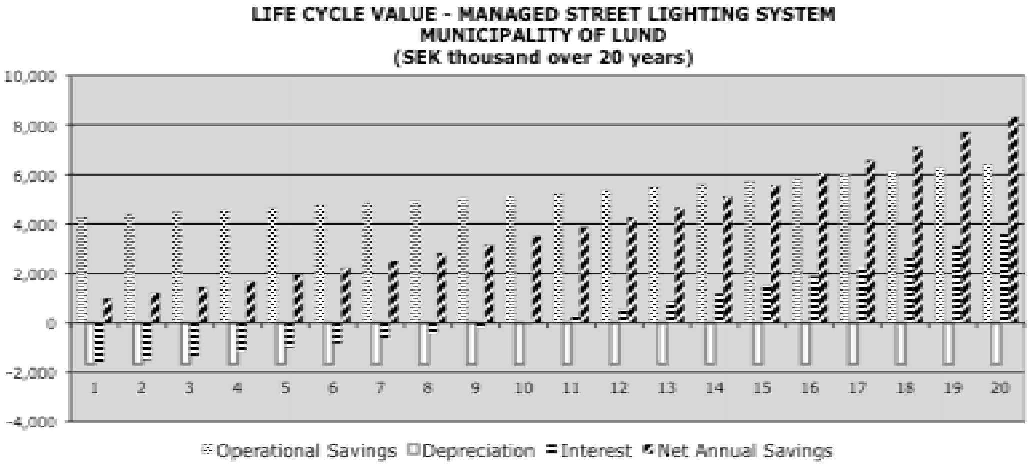

Figure 8 *Life cycle value*

In order to make proper use of tools such as the life cycle value tool, the municipal officer must possess the competence and necessary information regarding the best available technology, and be able to assess the life cycle costs of this technology. As we have found, technology ignorance creates an information barrier that must be overcome. One way of doing this is through the use of functional procurement, where the responsibility of making the assessment of the best available lighting technology is redirected towards an external party specializing in this field.

8.2 Functional Procurement

By stating functional requirements in the procurement process, as opposed to specifying the product or technology that shall satisfy the function, the technology ignorance barrier is reduced. While the municipal officer concentrates on formulating the functional qualifications that the product or technology must fulfill, the external supplier makes sure that the highest quality, most energy efficient technology meeting these qualifications is supplied. In such a way, the technical expertise of the supplier is utilized to the greatest extent.

An important part of this process is that the technology supplied is evaluated on the basis of life cycle cost/total cost of ownership. Therefore, the supplier should specify the life cycle cost of its products in the answer to the municipal tendering. By comparing the life cycle cost of the different alternatives that will be assessed during the functional procurement process, the most efficient technology with the lowest total cost can be chosen. These costs are then judged against the current life cycle costs in order to obtain the life cycle savings

An important barrier, however, remains. The procurement process is complicated, and many municipal officers do not possess the necessary competence to accurately assess their needs, which is imperative when utilizing functional procurement. The procurement process needs to be more clearly defined in terms of supporting guidelines and recommendations that will aid in making the process less demanding for municipal officers.

8.3 Performance Guarantees

One of the main grounds for the existence of a shortsighted investment horizon within municipalities is, as described earlier, the political risk associated with relying on the future results of long-term investments. There is a general fear of being held accountable for wrongful decisions, which is further fuelled, or even initiated, by the public insight into municipal operations and decision-making. Restrictions are thereby placed on the length of payback time that is accepted for any given investment. This shortsighted behavior leads to an investment policy that is centered around investments that yield immediate, short-term results. This obviously hinders more long-term, large-scale investments in energy efficient technology.

This barrier can be alleviated through the use of performance guarantees, which is one of the key components in energy performance contracting. By guaranteeing the level of savings that an energy efficiency investment will generate up until the investment is paid back, the financial risk is transferred from the municipality and its political decision-makers to the ESCO, due to the fact that if the guaranteed savings are not met, the ESCO is contractually obligated to pay the difference. This, in turn, ensures that the ESCO will do its best to verify the savings.

The use of performance guarantees presents a means to reduce the political uncertainty associated with an investment in energy efficient lighting technology. The investment horizon can be extended to accommodate the investment's payback time of roughly seven to ten years, because, from the politicians' perspective, the risk is reduced to virtually nothing. With this foundation, it might also be easier for politicians to promote the additional benefits, such as the environmental and social benefits of the investment, to municipal citizens.

9 Discussion

In the following chapter, we discuss the extent to which our solutions overcome the identified barriers, and apply an external market adoption perspective on managed street lighting.

Table 7 provides an overview of how the proposed solutions target the identified barriers to energy efficiency investments. As we can see, energy performance contracting is a central part of these solutions, as the use of both functional procurement and performance guarantees are inherent in this business model. Through the use of functional procurement, knowledge from technical experts at specialist companies can be transferred to the municipality. In addition, by providing performance guarantees, the investment horizon can be extended as the risk associated with future savings is minimized. The integrated maintenance and operator training further aids in reducing the functional and application uncertainty expressed by the operating technicians. The life cycle value approach aims to identify the savings, or profit, that will be derived from the investment, and by presenting a means by which the investment's capital costs can be funded, additional investment capital can be obtained, and the investment horizon lengthened.

However, as illustrated in table 7, energy performance contracting together with a life cycle value approach does not overcome all of the identified barriers to energy efficiency investments. The barrier of insufficient procurement competence remains, requiring further action from legislative and policy-making authorities.

Table 7 *Solution-barrier matrix*

	BARRIERS TO ENERGY EFFICIENCY			
SOLUTIONS	Technology Ignorance	Lack of Investment Capital	Insufficient Procurement Competence	Short-sighted Investment Horizon
Life Cycle Value				
Functional Procurement				
Guarantees				

When utilizing functional procurement, the municipal officers involved in the procurement process must have the competence to be able to specify the functional requirements that the procured technology must fulfill. Without this competence, functional procurement serves no higher purpose. The municipal officers have expressed confusion and difficulty in interpreting the Swedish Public Procurement Act's rules, with respect to the lowest price criteria, and particularly when acquiring products or services based on the most economically advantageous offer. With this in mind, functional procurement, which is even more rarely practiced, will most likely create a lot of headache among procurers. Therefore, the Swedish Competition Authority, in particular, must create much clearer guidelines for the use of functional procurement. In further supporting the municipal officers, additional assistance can be acquired through the use of specialized consulting firms with experience within the field of public procurement.

In our proposal of the adoption of a life cycle value approach, we have emphasized the economic benefits that this approach brings to light. This is due to the fact that, through our research, we concluded that decisions in municipalities regarding the choice of whether or not to invest often boils down to a question of economics. However, as public strategic logic shows, the strategy of local governments cannot be confined to any single objective, such as the maximization of profit. It is important that everyone within the municipal organization understands these additional driving forces. For example, the local politicians might not first and foremost be interested in reducing the municipal operating budget, but rather decreasing the environmental load, or increasing the safety of the citizens. Our life cycle value tool incorporates this in one dimension by translating the reductions in energy use to decreased CO_2 emissions. However, other dimensions such as the improved sense of safety through better lighting technology and its impact on the rate of crime are also important to consider.

The first step in developing a life cycle value approach should be to incorporate the necessary tools through which to evaluate investment decisions. This will help those closest to the technology, i.e. operating technicians, to discover the economic value associated with the investment, and present the right incentives towards the politicians in order to obtain additional investment capital. The responsibility of seeing to that these tools are in place should be assigned to the head of the technical administration. Education in life cycle costing should accompany the use of life cycle value tools in order to be able to determine all cost drivers across the life cycle of the technology. Secondly, the internal communication within municipalities must improve in order to fully understand the driving values present on each level within the municipality. This is evident, as the politicians, those in charge of municipal funds, have contradicted the municipal officers’ assertion of a lack of investment capital.

With the proposed solutions in mind, when, then, will we see a large-scale market adoption of managed street lighting? By turning to the 5A’s framework presented in chapter three, we can obtain insight into how far along managed street lighting technology has progressed in achieving market adoption. According to the framework, the technology needs to fulfill four critical steps in order to reach market acceptance. As seen in the E-street project in Oslo, the technology is apparently available. Consequently, the first step in the framework is hardly a roadblock. However, as our case study revealed, the operating technicians are rarely aware of the new lighting technology, indicating that the benefits of the technology have not been sufficiently documented and communicated to the mass market. When aware of the existence of the technology, we do not believe that accessibility is an issue for the end user. The fourth step, affordability, attends to the cost of procuring the technology. As seen in appendices 1-5, the cost of the equipment is still fairly expensive due to a limited market, and when not aware of the savings potential of the technology, the end user might be deterred from buying it. To summarize, in the case of managed street lighting technology, the 5A's framework shows that awareness and affordability are hindering the technology from reaching full market acceptance, highlighted in figure 9.

Figure 9 *The deficient market acceptance of managed street lighting*

Our proposed solutions may very well help bring managed street lighting closer to market adoption. However, as the theory of technology adoption states, when market failures such as these occur, government and regulatory bodies must become involved to facilitate greater levels of market adoption. For example, as mentioned above, the Swedish Competition Authority must provide clearer guidelines regarding the use of functional procurement.

10 Conclusions and Recommendations

In this final chapter, conclusions are drawn upon earlier findings, and theoretical, as well as practical contributions are highlighted.

Our findings show that energy performance contracting is an effective business model for targeting several of the identified barriers to energy efficiency investments, such as energy efficient street lighting technology. Through functional procurement, the municipality takes advantage of the technical expertise of industry experts, thereby overcoming the barrier of technology ignorance. Performance guarantees transfer the risk of long-term investments from the municipality to the service providing ESCO. Hence, the shortsighted investment barrier is alleviated due to the assurance of future savings that are generated by the investment. In addition, the integrated maintenance and operator training lessen the functional and application uncertainties that the operating technicians face when procuring new technology.

In order to overcome the lack of investment capital barrier, we recommend that municipalities, and especially municipal officers, adopt a life cycle value approach. This implies the incorporation of tools such as the one in appendices 1-5, accompanied by proper education within life cycle costing. It is by comparing the total costs of new technology with those of the existing installations that the savings potential becomes apparent. The savings potential will constitute a means by which to fund the additional capital costs incurred by the investment, providing motivational grounds for the allocation of additional investment capital. The life cycle value approach is particularly useful when acquiring products or technologies that are costly to operate and maintain.

It is also important that the municipal officers are aware of not only the economic value of the investment, but other values, such as environmental and social values, as well. Understanding the driving forces on the political level is crucial when internally marketing the investment towards politicians.

The barrier of insufficient procurement competence must be dealt with by authorities such as the Swedish Competition Authority by introducing clearer guidelines of how to perform functional procurement under the regulations stipulated by the Swedish Public Procurement Act.

Our thesis has aimed at identifying the most critical barriers to energy efficiency within local governments in Sweden, as well as providing practical solutions to these barriers. As earlier mentioned, previous research has focused on identifying barriers in a broader context, and the few solutions that have been proposed have mainly targeted state governments, and not local governments. We realize that through our limited research, we may not have identified all relevant barriers hindering energy efficiency investments. Nevertheless, we believe that they are the most essential in the context of Swedish local governments. Furthermore, our solutions, such as our life cycle value tool together with the EPC business model, are of practical nature, as opposed to the recommendations provided by the Swedish Government Official Reports. Our solutions provide the opportunity for local governments to assist themselves in overcoming barriers to energy efficiency.

Even though our case study has focused on one particular energy efficiency investment, we believe that our results are not only specific to public street lighting, but can be applied to other investments in energy efficiency as well. It would be interesting for future research to test this postulate, as well as examine the extent to which our proposed solutions can tackle barriers outside the scope of our thesis.

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Appendix 1 – Landskrona

LIFE CYCLE VALUE - Managed Street Lighting

Municipality of Landskrona

CONCLUSIONS	
Invested Capital (SEK)	28 438 769
Annual Savings (SEK)	3 589 040
Life Cycle Value (SEK)	63 421 952
Reduction of CO2 (tonnes)	44 001

To be filled in

ASSUMPTIONS		
Economic life	years	20
Annual (real) interest rate	%	0,05
Annual (real) energy price increase	%	0,03
Price of electricity	SEK/kWh	1,0
Number of streetlights	units	8 700
Operating hours per year (old installation)	hours	4 000
Hours of dimming	hours	2 625
Full blast	hours	1 375
Annual electricity consumption	kWh	4 176 000
Effect reduction, dimming	%	0,50
Effect reduction, luminaire		0,15
Effect reduction, lamp replacement	%	0,20
Residual value, exisiting installation	SEK	2 000 000

COST OF INVESTMENTS		Present	New	Difference
Lamp	SEK/unit	50	50	
Luminaire	SEK/unit	60	1 200	
Smart electronic dimmable ballast	SEK/unit		900	
Lamp system controller	SEK/unit		1 100	
Segment controller	SEK/unit		8 000	
Central management system	SEK		50 000	
Installation	SEK	0	0	
Other expenses	SEK	0	0	
Total cost of investment per luminaire	*SEK*	*110*	*3 379*	
TOTAL INVESTMENT	SEK	957 000	29 395 769	28 438 769

OPERATING COSTS				
Energy				
Energy use	kWh/year	480	219	
Cost of energy	SEK/year	480	219	
Lamp cost, incl replacement				
Lamp life	hours	16 000	24 000	
Lamp cost	SEK	50	50	
Annual cost of lamp, incl replacement	SEK/year	83	72	
Cost of maintenance				
Maintenance per luminaire	SEK/unit	104	13	
Unplanned maintenance	SEK/unit	50		
Operating costs per luminaire	*SEK*	*717*	*304*	
TOTAL OPERATING COSTS	SEK	6 233 550	2 644 510	3 589 040

Appendix 2 – Klippan

LIFE CYCLE VALUE - Managed Street Lighting

Municipality of Klippan

CONCLUSIONS	
Invested Capital (SEK)	15 503 932
Annual Savings (SEK)	1 953 758
Life Cycle Value (SEK)	35 188 653
Reduction of CO2 (tonnes)	23 953

To be filled in

ASSUMPTIONS		
Economic life	years	20
Annual (real) interest rate	%	0,05
Annual (real) energy price increase	%	0,03
Price of electricity	SEK/kWh	1,0
Number of streetlights	units	4 736
Operating hours per year (old installation)	hours	4 000
Hours of dimming	hours	2 625
Full blast	hours	1 375
Annual electricity consumption	kWh	2 273 280
Effect reduction, dimming	%	0,50
Effect reduction, luminaire		0,15
Effect reduction, lamp replacement	%	0,20
Residual value, exisiting installation	SEK	0

COST OF INVESTMENTS		Present	New	Difference
Lamp	SEK/unit	50	50	
Luminaire	SEK/unit	60	1 200	
Smart electronic dimmable ballast	SEK/unit		900	
Lamp system controller	SEK/unit		1 100	
Segment controller	SEK/unit		8 000	
Central management system	SEK		50 000	
Installation	SEK	0	0	
Other expenses	SEK	0	0	
Total cost of investment per luminaire	*SEK*	*110*	*3 384*	
TOTAL INVESTMENT	SEK	520 960	16 024 892	15 503 932

OPERATING COSTS				
Energy				
Energy use	kWh/year	480	219	
Cost of energy	SEK/year	480	219	
Lamp cost, incl replacement				
Lamp life	hours	16 000	24 000	
Lamp cost	SEK	50	50	
Annual cost of lamp, incl replacement	SEK/year	83	72	
Cost of maintenance				
Maintenance per luminaire	SEK/unit	104	13	
Unplanned maintenance	SEK/unit	50		
Operating costs per luminaire	*SEK*	*717*	*304*	
TOTAL OPERATING COSTS	SEK	3 393 344	1 439 586	1 953 758

Appendix 3 – Lund

LIFE CYCLE VALUE - Managed Street Lighting

Municipality of Lund

CONCLUSIONS	
Invested Capital (SEK)	60 416 923
Annual Savings (SEK)	7 631 867
Life Cycle Value (SEK)	137 166 233
Reduction of CO2 (tonnes)	93 565

To be filled in

ASSUMPTIONS		
Economic life	years	20
Annual (real) interest rate	%	0,05
Annual (real) energy price increase	%	0,03
Price of electricity	SEK/kWh	1,0
Number of streetlights	units	18 500
Operating hours per year (old installation)	hours	4 000
Hours of dimming	hours	2 625
Full blast	hours	1 375
Annual electricity consumption	kWh	8 880 000
Effect reduction, dimming	%	0,50
Effect reduction, luminaire		0,15
Effect reduction, lamp replacement	%	0,20
Residual value, exisiting installation	SEK	3 000 000

COST OF INVESTMENTS		Present	New	Difference
Lamp	SEK/unit	50	50	
Luminaire	SEK/unit	60	1 200	
Smart electronic dimmable ballast	SEK/unit		900	
Lamp system controller	SEK/unit		1 100	
Segment controller	SEK/unit		8 000	
Central management system	SEK		50 000	
Installation	SEK	0	0	
Other expenses	SEK	0	0	
Total cost of investment per luminaire	*SEK*	*110*	*3 376*	
TOTAL INVESTMENT	SEK	2 035 000	62 451 923	60 416 923

OPERATING COSTS				
Energy				
Energy use	kWh/year	480	219	
Cost of energy	SEK/year	480	219	
Lamp cost, incl replacement				
Lamp life	hours	16 000	24 000	
Lamp cost	SEK	50	50	
Annual cost of lamp, incl replacement	SEK/year	83	72	
Cost of maintenance				
Maintenance per luminaire	SEK/unit	104	13	
Unplanned maintenance	SEK/unit	50		
Operating costs per luminaire	*SEK*	*717*	*304*	
TOTAL OPERATING COSTS	SEK	13 255 250	5 623 383	7 631 867

Appendix 4 – Hässleholm

LIFE CYCLE VALUE - Managed Street Lighting

Municipality of Hässleholm

CONCLUSIONS	
Invested Capital (SEK)	43 008 408
Annual Savings (SEK)	4 714 511
Life Cycle Value (SEK)	66 215 807
Reduction of CO2 (tonnes)	52 683

To be filled in

ASSUMPTIONS		
Economic life	years	20
Annual (real) interest rate	%	0,05
Annual (real) energy price increase	%	0,03
Price of electricity	SEK/kWh	1,0
Number of streetlights	units	13 165
Operating hours per year (old installation)	hours	4 000
Hours of dimming	hours	2 625
Full blast	hours	1 375
Annual electricity consumption	kWh	5 000 000
Effect reduction, dimming	%	0,50
Effect reduction, luminaire		0,15
Effect reduction, lamp replacement	%	0,20
Residual value, exisiting installation	SEK	2 000 000

COST OF INVESTMENTS		Present	New	Difference
Lamp	SEK/unit	50	50	
Luminaire	SEK/unit	60	1 200	
Smart electronic dimmable ballast	SEK/unit		900	
Lamp system controller	SEK/unit		1 100	
Segment controller	SEK/unit		8 000	
Central management system	SEK		50 000	
Installation	SEK	0	0	
Other expenses	SEK	0	0	
Total cost of investment per luminaire	*SEK*	*110*	*3 377*	
TOTAL INVESTMENT	SEK	1 448 150	44 456 558	43 008 408

OPERATING COSTS				
Energy				
Energy use	kWh/year	380	174	
Cost of energy	SEK/year	380	174	
Lamp cost, incl replacement				
Lamp life	hours	16 000	24 000	
Lamp cost	SEK	50	50	
Annual cost of lamp, incl replacement	SEK/year	83	72	
Cost of maintenance				
Maintenance per luminaire	SEK/unit	104	13	
Unplanned maintenance	SEK/unit	50		
Operating costs per luminaire	*SEK*	*616*	*258*	
TOTAL OPERATING COSTS	SEK	8 113 523	3 399 012	4 714 511

Appendix 5 – Kristianstad

LIFE CYCLE VALUE - Managed Street Lighting

Municipality of Kristianstad

CONCLUSIONS	
Invested Capital (SEK)	75 100 769
Annual Savings (SEK)	9 388 332
Life Cycle Value (SEK)	165 127 412
Reduction of CO2 (tonnes)	114 386

To be filled in

ASSUMPTIONS				
Economic life	years	20		
Annual (real) interest rate	%	0,05		
Annual (real) energy price increase	%	0,03		
Price of electricity	SEK/kWh	1,0		
Number of streetlights	units	23 000		
Operating hours per year (old installation)	hours	4 000		
Hours of dimming	hours	2 625		
Full blast	hours	1 375		
Annual electricity consumption	kWh	10 856 000		
Effect reduction, dimming	%	0,50		
Effect reduction, luminaire		0,15		
Effect reduction, lamp replacement	%	0,20		
Residual value, exisiting installation	SEK	5 000 000		
COST OF INVESTMENTS		**Present**	**New**	**Difference**
Lamp	SEK/unit	50	50	
Luminaire	SEK/unit	60	1 200	
Smart electronic dimmable ballast	SEK/unit		900	
Lamp system controller	SEK/unit		1 100	
Segment controller	SEK/unit		8 000	
Central management system	SEK		50 000	
Installation	SEK	0	0	
Other expenses	SEK	0	0	
Total cost of investment per luminaire	*SEK*	*110*	*3 375*	
TOTAL INVESTMENT	SEK	2 530 000	77 630 769	75 100 769
OPERATING COSTS				
Energy				
Energy use	kWh/year	472	216	
Cost of energy	SEK/year	472	216	
Lamp cost, incl replacement				
Lamp life	hours	16 000	24 000	
Lamp cost	SEK	50	50	
Annual cost of lamp, incl replacement	SEK/year	83	72	
Cost of maintenance				
Maintenance per luminaire	SEK/unit	104	13	
Unplanned maintenance	SEK/unit	50		
Operating costs per luminaire	*SEK*	*709*	*300*	
TOTAL OPERATING COSTS	SEK	16 295 500	6 907 168	9 388 332

Appendix 6 – Lighting Glossary

Some of the most commonly used terminology, in terms of street lighting, is presented in this appendix. If not otherwise specified, the definitions originate from GE Lighting (www.gelighting.com). For a more detailed understanding, the reader is referred to, for example *IES Lighting Handbook – Reference Volume by Illuminating Engineering Society of North America*.

Arc. Intense luminous discharge formed by the passage of electric current in a gaseous medium across a space between electrodes.
Ballast. An auxiliary piece of equipment required to start and to properly control the flow of current to gas discharge lamps such as fluorescent and high intensity discharge (HID) lamps. Typically, magnetic ballasts (also called electromagnetic ballasts) contain copper windings on an iron core while electronic ballasts are smaller and more efficient and contain electronic components.
Candela (cd). The measure of luminous intensity of a source in a given direction. The term has been retained from the early days of lighting when a standard candle of a fixed size and composition was defined as producing one candela in every direction. A plot of intensity versus direction is called a candela distribution curve and is often provided for reflectorized lamps and for s with a lamp operating in them.
Color temperature. Color temperature relates to whether the light emitted by a certain lamp is perceived as warm, white or cold. Measured in Kelvin, the lower the color temperature, the more yellow the light is perceived. At higher color temperatures, the lamp gives off a more bluish-white light.
Color-rendering index (CRI). This refers to the ability of the lamp to render object colors in the surrounding environment. CRI is based on a 0-100 scale, where the higher the value the richer the colors appear. Daylight, with a CRI of 100, gives the ideal color rendering. For lamps, a CRI of over 70 is preferred.
Dimmable. Whether or not the lamp lumens can be varied while maintaining reliability.
Disability glare. Glare that impairs the visibility of objects without necessarily causing discomfort.
Discomfort glare. Glare that causes discomfort without necessarily impairing the visibility of objects.
Efficacy. A measurement of how effective the lamp is in converting electrical energy to lumens of visible light. Expressed in lumens-per-watt (LPW) this measure gives more weight to the yellow region of the spectrum and less weight to the blue and red region where the eye is not as sensitive.
Efficiency. The efficiency of a lamp is simply the fraction of electrical energy converted to light, i.e. watts of visible light produced for each watt of electrical power with no concern about the wavelength where the energy is being radiated. For example, a 100 watt incandescent lamp converts 7% of the electrical energy into light; discharge lamps convert 25% to 40% into light. The efficiency of a or fixture is the percentage of the lamp lumens that actually comes out of the fixture.
Electrical Discharge. A condition under which a gas becomes electrically conducting and becomes capable of transmitting current, usually accompanied by the

emission of visible and other radiation. An electric spark in air is an example of an electrical discharge, as is a welder's arc and a lightning bolt.

Fluorescent. Emitting light of one color or a range of colors (usually human visible) when light of another color (usually ultraviolet) is shone upon it. The fluorescent lamp would give off no more than a dim bluish glow plus produce a lot of ultraviolet light mostly absorbed by the glass tube were it not for the fluorescent material (called phosphors) coating the inside of the tube. Mercury vapor lamps also produce ultraviolet light and are often coated with phosphors so they give off white light for more natural looking illumination in addition to the bright bluish (green-purple) glow of the mercury arc.

Glare. Condition of vision in which there is discomfort or a reduction in ability to see, or both, caused by an unsuitable distribution or range of luminance, or to extreme contrasts in the field of vision.

Halide Lamp. A mercury lamp containing chemical compounds involving halogens so that the light produced is whiter compared with the green-purple glow from a pure mercury vapor lamp.

Halogen lamp. An incandescent lamp whose bulb is filled with one or a mixture of halogens in order to cause material naturally evaporating from the filament to tend to redeposit on the filament and thus make the filament last longer.

HID (High Intensity Discharge). Generally refers to a mercury, mercury & metal halide, or sodium lamp. The electric arc ,or discharge, passing through mercury vapor, sodium vapor, etc. produces an intensely bright glow.

Lamp. The term used to refer to the complete lamp package, including the inner parts as well a the outer bulb or tube. "Lamp", of course, is also commonly used to refer to a type of small light fixture such as a table lamp.

Lumen. A measure of the gross light output from the lamp. A higher lumen is a brighter lamp.

Luminance, L. Luminance is the measure of “surface brightness” when an observer is looking in the direction of the surface, and is measured in Candela (cd) per square meter.

Illuminance. This is the measure of light density, or level of light, on a given surface. Illuminance is measured in Lux. (1 Lux = 1 cd/m2).

Luminous intensity, I. The concentration of luminous flux emitted in a specified direction. Unit: candela (cd).

Luminous flux, φ. This refers to the total quantity of light emitted by a lamp. Luminous flux is measured in Lumen (lm).

Luminous intensity, I. Luminous intensity is the measure of light that is emitted in a certain direction by a lamp. It is measured in Candela (cd).

Lux, lx. A unit of illuminance or light falling onto a surface. One lux is equal to one lumen per square meter. Ten lux approximately equals one foot-candle.

Photometry. The measurement of light and related quantities.

Power. The power of a lamp refers to the level of energy that is consumes per unit of time. It is measured in Watts (W).

Reflector. Any polished or light colored object intended to aim (by "bouncing") light in a desired direction as opposed to just block or absorb it.