Economic feasibility of replacing sodium vapor and high pressure mercury vapor bulbs with LEDs for street lighting

Olusola Olorunfemi Bamisile, Mustafa Dagbasi, and Serkan Abbasoglu

ABSTRACT
The main aim of this article is to examine the feasibility of an energy audit program. LEDs are used to replace the sodium vapor lamps and high-pressure mercury vapor lamps that are currently used for the street lighting system in the Turkish Republic of Northern Cyprus. 44% of the fossil fuels imported into the Turkish Republic of Northern Cyprus is used for electricity generation, which makes the reduction in the consumption of electricity very important. This project will save as much as 36,880,410 kWh on site annually and 111,758,818 kWh from the source. The economic, environmental, and fossil fuels savings of this project are also evaluated.

1. Introduction
Reduction in the amount of energy required to provide equal service and product is one of the primary goals of an energy efficiency program, although saving cost is given the highest priority. Energy efficiency involves the use of technologies that require less energy to perform the same comfort service and same function, and this has a major role to play in all countries’ energy sector. According to the International Energy Agency, improved efficiency in buildings, transportation, and industrial processes could reduce the world’s energy consumption by one third within the next 30 years, and this will play a major role in carbon emission reduction. Energy efficiency is the cleanest form of untapped energy resources available globally.

Electricity consumption in a developed country experiences a growth rate of 1% per year as opposed to 5% witnessed in other developing countries. The world’s electricity consumption is expected to double the rate it was in the year 2010 by 2020 if the consumption rate maintains the upward growth trend. The industrial revolution in the 1970s led to the increase in electricity consumption with varieties of technology introduced around that period, and it has made electricity “an indispensable commodity” in the 21st century. Fossil fuel, which accounts for 77.9% of the world’s total electrical source, is a major threat to the environment due to its high greenhouse gas (GHG) emission content. According to the World Health Organization (WHO), over 250,000 people died in 2014 as a result of direct and indirect effects of climate change, and this is expected to double by 2020.

Street lighting is a significant energy (electrical) consumer in every society. It constitutes a major part of the municipal energy expenditures and consumption, costing up to 40% of an average society municipalities’ energy bills. Street lighting systems are on for about 9 to 12 hours daily on average, which makes it consume a large amount of energy. With the major aim of lighting the edges of roads and also adding more illumination to major roads, street lighting systems have witnessed some development in terms of the type of bulb used. The first widely used street light was piped by gas-coal fuel. This was invented in the early 18th century, and since then, many inventions have taken place, including HPMV lamps, SV lamps, and LED bulbs. The use of LEDs has become an efficient alternative considering the municipalities’ bills. A system-wide conversion can lead to an opportunity to standardize the municipality of a society in addition to the economic and environment benefits offered by LEDs. The advantages of using LED lighting include:

- Decrease in energy consumption
- No start-up losses
- Improved commitment to energy efficiency
- Reduced maintenance expenses as a result of longer lifespan
- Hazardous chemicals such as mercury, lead, and other disposals are not involved

Energy audit/energy management being the bedrock of most energy efficiency projects, an energy audit of the street lighting system of an island (Turkish Republic of Northern Cyprus) is the focus of this study. The environmental and economic analysis of this project is fully discussed, with much focus on reduction of cost.

The energy sources and electricity generation trends and consumption of the Turkish Republic of Northern Cyprus was...
carried out by Abbasoglu et al. In the study, a proper energy audit was carried out on a typical office building, and the economic and environmental feasibility and effects of some proposed energy efficiency applications were calculated. The net present value (NPV), savings to investment ratio (SIR), internal rate of return (IRR), and simple payback period (SPP) of applying wall insulation, roof insulation, window replacement, and new air conditioning systems were calculated. Although the whole project was economically feasible, individual economic feasibility shows that replacing the windows was not feasible, while others were feasible and also environmentally friendly.

Possible energy savings potential was considered with some changes made in the illumination schemes in Ref. 12, and a case study of replacing existing convective lighting systems with LED lighting schemes in an engineering institute was considered. Also, an intelligent approach was made to the use of LEDs for street lighting, and this application is based on the use of wireless communication to minimize the investment cost compared to the traditional wired system. Other research on street lighting systems focuses majorly on the use of LEDs in conjunction with the use of remote control systems that send information from intelligent lamp posts to a central control system regarding maintenance issues and management.

According to Narendra and Devendra, the comfort level was not decreased in a bid to save more energy, and LEDs have the major advantage of a longer lifetime compared to other lighting systems. Also, LEDs’ consumption of little electrical energy makes it far better than any illuminating/lighting systems, including compact fluorescent lamps (CFLs). A simple payback period of 14 months based on investment and running cost was calculated for the whole project using LEDs, whereas it is 6 months using CFLs, but it was clearly stated that the durability of CFLs (5,000–7,000 hours) against that of LEDs (30,000–50,000 hours) gave it an edge if the calculation is made based on a longer duration. In Elejoste et al.’s study, the environmental conditions are put into consideration, and the knowledge of real time for illumination was used. This gave an exact calculation of energy consumption and also a dependent mechanism for maintenance of facilities. A similar study has also been carried out on the developed cities in the United States.

2. Model of energy utilization and cost evaluation

The case study for this research is the Turkish Republic of Northern Cyprus. A total of 60,000 street lighting bulbs/lamps are used in the street lighting for both major and minor roads in TRNC. According to Kib-Tek (TRNC, electricity board), there are 30,000 bulbs/lamps used for the major (express) roads lighting, and the other 30,000 are used on the roads within the city (streets). A two bulbs to one pole lighting system is used on big roads and on some of the streets.

It was observed in the walk-through audit that the bulbs are 12 m above ground level for the major roads and 6 m within the city, and also the distance between two street lighting systems within the city is 30 m and that of major roads is 50 m. SV lamps with a power rating of 250 watts are used for proper illumination on the major roads, while 125-watt HPMV bulbs are used within the cities. The street lighting is observed to work for an average of 11 hours/day annually.

A preliminary energy audit and also a walk-through audit is the main method used in collecting the data used for this research. Some information used in this research collected from Kib-Tek Numerical analysis is used in calculating the economic and environmental feasibility of this project. A life cycle cost (LCC) analysis using a minimum attractive rate of return (MARR) and the savings to investment ratio (SIR) is done. With the analysis done over a period of 90 months, the main aim of this research is to check environmental savings made over this period using LEDs and also the financial balance of replacing the total 60,000 street lighting system. The simple payback period (SPP) of the new project is also calculated using a numerical method. The environmental feasibility of this study is calculated against using a thermal power plant that uses #6 fuel oil.

2.1. Calculations

The data used for all the calculations in this study are stated in Table 1. For all the calculations, the starter losses for the HPMV and SV lamp are ignored. It is also assumed that the cost of street lighting bulbs is constant over a period of 90 months. It should also be noted that the heat content of coal and petroleum varies, depending on the coal type or the petroleum product. Table 2 shows the street lighting bulb
 specifications in terms of wattage and luminous flux. Tables 3 and 4 state the results from all the calculations. While Table 3 shows the economic figures, Table 4 states the annual energy savings that will be made.

The following set of equations is used to make the calculations for this study. The results from this set of calculation are shown in Table 3.

\[ IIC = TNB \times \left[ \text{Cost of Each Bulb} + \text{Installation Cost} \right] \]  

\[ AOT = AODC \times 365 \text{days} \]  

\[ TP = TNB \times \text{Bulb Wattage} \]  

\[ EC = TP \times AOT \]  

\[ MC = EC \times BW \]  

\[ RP = \text{lamp lifetime} / \text{AOT} \]  

In order to state the environmental importance of this study and its energy security effect, the energy savings are calculated using equation 7 to equation 9, and the results are displayed in Table 4.

\[ AES = \text{Old Technology Annual Energy Consumption} - \text{LED Annual Energy Consumption} \]  

\[ ASES = \text{Site Energy Savings/Electric Production (including distribution losses) Efficiency} \]  

\[ AER (\text{#6 fuel oil}) = \text{Emission Factor} \times ASES \]  

### 2.2. Economic analysis

The present worth for the existing system is compared with LED installation for a period of 90 months in Table 5. An add-in Excel application is used to make this calculation.

The following equations are used in making other economic analysis calculations, and the results of the calculations are clearly stated in Table 6.

\[ SPP = \frac{\text{Initial cost difference}}{\text{Monthly energy cost difference}} \]  

\[ SIR = \frac{PW_s}{PW_i} \]  

\[ PW_i = P_n - \left\{ P_1 + P_2 (P/F, i, n_2) + P_3 (P/F, I, n_3) \right\} \]  

where

- A = monthly cost savings
- \( P_n = IIC_o \)
- \( P_1, P_2, P_3 = IIC_o \) = investment at month 0, month 30, and month 60
- \( n_2, n_3 = 30 \) and 60 months, respectively
- \((P/F, i, n)\) = interest factor

Note that subscripts n and o represents new and old technology, respectively.

### 3. Results and discussion

This section presents the results of an energy audit program on the TRNC street lighting system. LEDs are used to replace SV and HPMV bulbs currently in use, and the economic feasibility is calculated. The GHG emission savings for this project and fossil fuel savings are also calculated and shown in the previous section. The results from the calculations are discussed in detail below.

An economic feasibility study was conducted with some basic assumptions such as:

- Negligible starter losses for the HPMV and SV lamp used.
- The buying price of street light is constant over a period of 90 months.

The total simple savings calculated when LEDs are used in place of the existing street lighting lamps over a period of 90 months, without putting the interest rate of the investment into consideration, is 120,545,981 TL. Considering the interest rate on the investment cost, the savings will reduce by at least 1%. Also, this amount is a strong indicator that the project is feasible economically. There are limitations to this project being a saving project; the life cycle costing analysis is limited to just PW, SIR, and SPP. This limitation is because the street
lightning system is managed by the government and is more of a community necessity than profit oriented.

Using an interest rate of 1% monthly, the present worth of the two technologies (using old technology or LEDs) are calculated over a period of 90 months. The project with the greater PW value (the one with lower expenditure) is said to be better than the other project. The result is summarized in Table 4.

A comparative SPP, which is the time duration for the project to recoup its initial cost if approved, is calculated in months for this study (Table 6). This is done by dividing the initial cost difference for the use of LEDs or SV and HPMV by the monthly energy cost difference over a period of 90 months. The new technology will pay back its investment 10 months earlier than stipulated for the old technology. The SPP of the LED lighting project itself is 16 months.

A dimensionless measure of performance is known to be the SIR of a project, which is also calculated over a period of 90 months for this study and the net savings being expressed in TL. SIR has no unit, and if the SIR of a project is greater than one (SIR > 1), the project is said to be feasible. The SIR for this project is calculated to be 4.49, which makes it very feasible (Table 6).

As fossil fuels are expected to deplete at the end of this 21st century, it is also important to put fossil fuel savings into consideration while performing an energy audit. In this study, coal, natural gas, and petroleum that may be saved due to the replacement of the entire street lighting system is calculated. The results show that 117,346,759 pounds of coal or 1,248,764 Mcf of natural gas or 195,578 barrels of petroleum will be saved if this project is carried out.

Carbon dioxide (CO₂), water vapor, nitrous oxide (N₂O), methane (CH₄), and ozone (O₃) constitute the main components of greenhouse gases. Reducing the emission of these gases in the atmosphere will improve the climate of the world. These gases basically prevent the emission of infrared radiation from the atmosphere, although they allow the entrance of solar radiation. The outgoing radiations are trapped in the atmosphere by GHG and then are re-emitted as thermal radiation, which in turn warms the earth surface. The relevant GHG that are calculated in this study include CO₂, SO₂, and NOₓ. The replacement of the street lighting system of TRNC will save as much as 29,392,569 kg of CO₂, 83,036.8 kg of NOₓ, and 164,285.5 kg of SO₂ annually from being emitted to the atmosphere.

The emissions from the combustion of fossil fuels are proven to influence human health negatively. Many respiratory-related health problems are related to SO₂ and CO₂. Reduction in these emissions surely will reduce the related health issues and, hence, reduce personal and governmental expenditures on such cases. For small and developing countries such as TRNC, where some health cases are treated abroad, reduction of emissions will improve the health structure and reduce the mortality rate.

The initial investment of this project is high, and individual/private organizations may not be able to finance the project. Provision of incentives/subsidies to local utilities by the government will encourage and speed up the change. A policy to implement the use of LEDs for street lighting especially within the streets will reduce emission effects and also reduce energy consumption and indirectly reduce emission-related illnesses and expenditures on this type of illness. Countries that import almost all their energy resources have high energy insecurity, and the reduction in fossil fuel consumption surely will improve energy security.

Although the lumens of LEDs for the case study are three times less than that of HPMV and SV bulbs, the emissions and fossil fuel savings by this project is worth the investment. Considering the energy security and climate change effect on TRNC, implementing this project is of more advantage. The TRNC economy is very much depending on tourism and university education. It is known that some 300,000 tourists visit the island annually, and there are about 50,000 foreign students studying in the universities established in TRNC. The reduction in emissions will positively affect the tourists and students.

4. Conclusions

The economic and feasibility calculations done in this study are based on the data collected through an energy audit program. Although the initial cost of using LEDs compared to using the existing technology in the street lighting system of TRNC seems very high, the feasibility of this project over a period of 90 months is highly positive. About a 1:8 ratio is recorded from the economic feasibility study carried out for this research, and this could be higher since the minimum expected lifetime of LED bulbs (30,000 hours) is used for the calculations.

In addition to the remarkable economic feasibility of this study, the environmental dividend of adopting the new technology is a plus to the energy world. About 32,523,111 kg of CO₂, 91,881 kg of NOₓ, and 181,783 kg of SO₂ are expected to be saved from being emitted to the atmosphere.

Implementing a project like this will not only save money for the country but also save the emission rate of the country and reduce (minutely) the rate of use/import of fossil fuels. A project such as this should also be encouraged in other third world countries, especially in Africa.

Despite the positive and good results attained by replacing the street lighting system with LEDs, the luminous flux of SV and HPMV bulbs are 3 times better than that of LEDs. It should be noted that less attention was paid to the technical calculations (lighting level) for this article since the scope is checking the economic feasibility.

**Abbreviations**

- AER: Annual emissions reductions
- AES: Annual energy savings
- AODC: Average daily operating cost
- AOT: Annual operating time
- ASES: Annual source energy savings
- BW: Bulb wattage
- CFL: Compact fluorescent lamps
- EC: Monthly energy consumption
- GHG: Greenhouse gases
- HPMV: High pressure mercury vapor
Subscripts

o Old technology
n New technology
i Investment
s Savings

References

[1] Hebben, S. Invest in Clean Technology Says IEA Report, June 22, 2006. http://www.scidev.net/en/news/investin-clean-technology-says-ia-report.html (accessed February 3, 2010).
[2] Fanchi, J. R. Energy: Technology and Directions for the Future. Elsevier Academic Press: London, 2004.
[3] Abbasoglu, S.; Demir, G.; Matur, Z.; Türkkan, M.; Düşünceli, B. Y. Energy Trend and Energy Efficiency in Turkish Republic of Northern Cyprus. 5th International Ege Energy Symposium and Exhibition (IEESE-5), June 27–30, 2010, Pamukkale University, Denizli, Turkey.
[4] International Energy Agency. http://www.iea.org.
[5] Vanek, F. M.; Albright, L. D. Introduction. In Energy Systems Engineering Evaluation and Implementation, 2nd ed.; McGraw-Hill: New York, 2012; 1–3.
[6] Bamisile, O. O. A Review of Solar Chimney Technology: Its Application to Desert Prone Villages/Regions in Northern Nigeria. Int. J. Sci. Eng. Res. 2014, 5, 1210–1216.
[7] Renewable Energy Policy Network for the 21st Century. 2011 Global Status Report, 2014.
[8] World Health Organization. http://www.who.int.
[9] Metropolitan Area Planning Council (MAPC). Retrofit Streetlights with LEDs. http://www.mapc.org/system/files/bids/Retrofit%20Streetlights%20with%20LEDs.pdf (accessed May 5, 2015).
[10] Thomson, J. The Scot Who Lit the World, The Story of William Murdoch Inventor of Gas Lighting; Janet Thomson, 2003.
[11] Fotios, S.; Cheal, C. Using obstacle detection to identify appropriate illuminances for lighting in residential roads. Lighting Res. Tech. 2013, 45, 362–376.
[12] Soni, N. B.; Devendra, P. The Transition to LED Illumination: A Case Study on Energy Conservation. J. Theoretic Appl. Info. Tech. 2008, 4, 1083–1087.
[13] P. Elejoste; I. Angulo; A. Perallos; A. Chertudi; I. J. García Zuazola; A. Moreno; L. Apilicueta; J. J. Astrain; F. Falcone; J. Villadangos. An Easy to Deploy Street Light Control System Based on Wireless Communication and LED Technology. Sensors 2013, 13, 6492–6523.
[14] Costa, M. A. D.; Costa, G. H.; dos Santos, A. S.; Schuch, L.; Pinheiro, J. R. A High Efficiency Autonomous Street Lighting System Based on Solar Energy and LEDs. In Proceedings of the Power Electronics Conference, Bonito-Mato Grosso do Sul, Brazil, 27 September–1 October 2009; 265–273.
[15] Chen, P. Y.; Liu, Y. H.; Yau, Y. T.; Lee, H. C. Development of An Energy Efficient Street Light Driving System. In Proceedings of the IEEE International Conference on Sustainable Energy Technologies, Singapore, 24–27 November 2008; 761–764.
[16] Wang, Y. Q.; Hao, C. C.; Zhang, S. L.; Huang, Y. L.; Wang, H. Design of Solar LED Street Lamp Automatic Control Circuit. In Proceedings of the Int. Conference on Energy and Environment Technology, Guilin, China, 16–18 October 2009; 90–93.
[17] Wu, Y.; Shi, C. H.; Zhang, X. H.; Yang, W. Design of New Intelligent Street Light Control System. In Proceedings of the 8th IEEE International Conference on Control and Automation (ICCA), Xiamen, China, 9–11 June 2010; 1423–1427.
[18] Caponetto, R.; Dongola, G.; Fortuna, L.; Riscica, N. Zufacchi, D. Power Consumption Reduction in A Remote Controlled Street Lighting System. In Proceedings of the International Symposium on Power Electronics, Electrical Drives, Automation and Motion, Ischia, Italy, 11–13 June 2008; 428–433.
[19] Chen, Y.; Liu, Z. Distributed Intelligent City Street Lamp Monitoring and Control System Based on Wireless Communication Chip nRF401. In Proceedings of the International Conference Networks. Security, Wireless Communication. Trusted Computing, Wuhan, China, 25–26 April 2009; 278–281.
[20] Lin, J. Y.; Jin, X. L.; Mao, Q. J. Wireless Monitoring System of Street Lamps Based on Zigbee. In Proceedings of the 5th International Conference on Wireless Communications, Networking and Mobile Computing, Beijing, China, 24–26 September 2009; 1–3.
[21] Liu, D.; Qi, S.; Liu, T.; Yu, S. Z.; Sun, F. The Design and Realization of Communication Technology for Street Lamps Control System. In Proceedings 4th International Conference Computer Science and Education, Nanning, China, 25–28 July 2009; 259–262.
[22] Street Lighting in New York State: Opportunities and Challenges; New York State Energy Research and Development Authority. Final Report December 2014. Revised January 2015. Report Number 14-42. http://www.nyserda.ny.gov/.
[23] Kıbrıs Türk Elektrik Kurumu. http://www.kktckb.org/tr/index.php/faiz-oranlari/ (in Turkish) (accessed May 11, 2015).
[24] Independent Statistics and Analysis U.S. Energy Information Administration. http://www.eia.gov/tools/faqs/faq.cfm?id=667&t= 8.
[25] Blank, L.; Tarquin, A. Basics of Engineering Economy. McGraw-Hill: New York, 25–100.
[26] Faiz Oranlari, Kalkima Bankasi. http://www.kibtek.com/Tarife01022015.pdf (accessed May 9, 2015).
[27] Product catalog, Professional lighting, PHILIPS lighting. http://www.lighting.philips.com/ (accessed April 10, 2016).