Energy Efficiency of Zoos: An Interdisciplinary Challenge with Special Benefits in Urban Environments

Sigrid Kusch
Institute for Sanitary Engineering, Water Quality and Solid Waste Management
University of Stuttgart
Stuttgart, Germany

Abstract— **Complex zoo habitats with a variety of artificially designed near-natural habitats are characterized by a huge consumption of energy and resources, which contradicts the missions of biodiversity conservation and resources protection. Aside of environmental aspects and educational impact related to installations operated visible for the visitors and to accompanying information campaigns, contribution of shining zoo energy projects towards sustainability lies in the creation of a unique element of identification by addressing the benefit of community power, generation of renewable energy in an urban environment, provision of financial reward for zoo supporters and by encouraging participation of people living in proximity.**

Keywords- renewable energy; energy efficiency; zoo waste; anaerobic digestion; bioenergy in urban areas

I. Introduction

Modern zoos are more than menageries. They care about conservation of biodiversity and resources, and are sites of research and education. According to the World Association of Zoos and Aquariums more than 700 million people visit zoos and aquariums each year (equal to 11% of the global human population).

Among the negative effects of diversified and complex zoo habitats is a huge consumption of energy, water and other resources. Animal houses with tropic climate throughout the whole year are one example for particularly high energy consumption.

Each site however is different, and as a consequence consumption of resources is very specific. An analysis of the profiles of German, Swiss and Austrian zoos (based on data published by [1]) revealed a wide range of specific energy consumption per land surface (also see Fig. 1) and per animal [2]:

- Electricity demand (n=11): 0.52 to 26.32 kWh/(m²*a), with a mean value of 7.42 kWh/(m²*a), or 26.13 to 1,978.38 kWh/(animal*a), with a mean value of 553.09 kWh/(animal*a)
- Heat requirement (n=12): 0.31 to 95.45 kWh/(m²*a), with a mean value of 19.43 kWh/(m²*a), or 36.29 to 2,445.95 kWh/(animal*a), with a mean value of 1,012.23 kWh/(animal*a)

Owing to the fact that structures of zoological sites (and in many cases accompanying botanical areas) are highly inhomogeneous and moreover as a consequence of the problem that scientific literature on the topic is very scarce, it is difficult to work out general recommendations for improving energy balances of zoos. Therefore zoo energy efficiency projects are special challenges.

Aside of striving to achieve environmental and economic benefits, zoo energy projects have special attractiveness and hold capacity to serve as shining examples for energy efficiency and installation of renewable energy in particular within an urban context. This paper looks at key elements in this context.

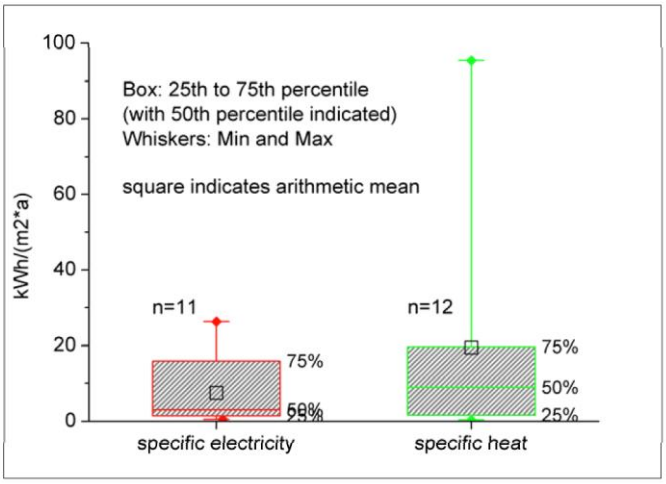

Figure 1. Specific electricity and heat demand of zoological gardens in Germany, Austria and Switzerland (in kWh per m² land surface area and per year; the analysis is based on data provided by [1] as result of an enquiry by questionnaire) [2]

II. Energy Efficiency in Zoo Environments

A. Improving the Energy Balance

Manifold approaches to reduce energy demands of zoological sites exist and are implemented in practice with success. An overview of zoo energy projects in German speaking countries has been published [1]. Innovations concerning the actual buildings are among the most efficient measures (resulting mainly in reduced heat losses). This includes up-to-date insulation, intelligent heating systems and provisions, and implementation of energy efficient building concepts wherever feasible. Solar heating of water areas, heating with wood (e.g. taken from the zoo ground), alternatively fuelled cars and vehicles are some excellent approaches to reduce energy demand of the sites through application of renewable energy, and are in full response to the demand to reduce the ecological footprint.

Biomass boilers fuelled with woody materials originating from the site are common. Generation of energy within the boundaries of a zoo (and if available the accompanying botanical sites – or in some cases the idea might also be applicable for solely a botanical garden) is a particularly well suited option for improving the energy balance.

Renewable energy generation within the zoo boundary (in particular when accompanied by additional explanations and if possible embedded in an area specifically devoted to the topic renewable energy) has a particularly high educational benefit and reaches a large and diversified target group, which holds high potential to act as multiplier for the topic.

The distinct heat demand of animal habitats and the fact that considerable heat demand needs to be covered throughout the whole year enable a very high total energy efficiency degree when implementing Combined Heat and Power (CHP) installations.

B. Renewable Energy from Zoo Waste

Utilisation of waste materials from the zoological site has potential for renewable energy generation. Among the most promising approaches is the valorisation of organic residues. Different approaches exist, and although valorisation of organic material is not a new idea, there is still high potential for innovation and implementation. One example are gasified pellets made from animal droppings and waste generated by zoo visitors and employees which are used to fuel rickshaws in the zoo of Denver since some months (the technology was developed by zoo employees, the patent is pending).

Zoo-derived organic materials are suitable to be used for biogas production through anaerobic digestion (AD) [2][3], resulting in an energy carrier for the generation of electricity, heat or as vehicle fuel.

A very large proportion from overall waste is to be characterized as organic. Therefore renewable energy generation based on valorisation of organic waste streams does not only increase overall energy efficiency of the site, but at the same time it significantly contributes to improved waste management. At present organic waste materials from zoological or botanical gardens are in general either composted on site or delivered to external treatment. Herbivore and carnivore dung is often separated, which is due to its different characteristics during treatment processes and due to the associated risks. In addition to wastes from animal habitats (i.e. slurry and dung, fodder residues, litter material, green wastes) organic wastes originate from botanical sites, from park areas/ planted areas, and from visitor spaces (this includes leftovers/ food waste from restaurants, biowastes, and sanitation materials).

C. AD with Zoo Waste

AD with biogas production has already been or is about to be implemented in some zoos (e.g. Munich, Heidelberg, Toronto, Johannesburg).

Figure 2. Plug-flow digester followed by stirred after-digester for the digestion of organic materials at the zoo in Heidelberg [5]

Biogas is further under research at some sites, but plans have also been given up at different sites. Successful implementation of AD faces a number of both technical and economic challenges [2]:

- The overall amount of available organic materials is limited, and in particular when including botanical sites varies with the seasons. It is particularly difficult to achieve economic viability for such small-scale installations.
- Most zoos are not under private management but in responsibility of the respective city or the upper level authority. This can result in complex planning and financing scenarios according to the specific circumstances and the involved authorities. The same is the case for the decision phase and for contracting of the AD plant supplier.
- Amounts and types of materials differ significantly from one site to another. As a result, transfer of specific know-how between sites is limited and each zoo AD project is unique.
- Hardly any data relevant for biogas production (biogas yields of mono substrates, digestion of mixtures, and requirement for micro nutrients supplementation) are available for zoo materials.
- Due to the characteristics of the materials, the majority of substrates will be rather slowly degradable without pre-treatment, and expectable biogas yield is rather low. This is a drawback with regard to economic viability of such an AD plant.

- Many of the potentially digestable substrates contain high amounts of lignocellulosic fractions (solid dung containing straw, tree and bush cut), and may also contain stones and high amounts of sand. These materials are unsuitable for running conventional wet AD systems; problems are likely to occur e.g. related to feeding and mixing equipment, and there is a particular high risk for stratification in the digester (comparable to problems encountered with digestion of horse manure [4]).

As discussed in [2], possible solutions for coping with the technical challenges related to process technology requirements are dry digestion in box-type fermentation systems (implemented at the Zoo Hellabrunn in Munich) or operation of a plugflow system (e.g. to be found at the zoo in Heidelberg, Fig. 2).

Main criteria when deciding in favour or against building an AD plant is economic viability, which can be improved by several factors [2]:

- simple and robust technology, which however can make use of very different kinds of substrates (e.g. zoo in Johannesburg)
- underpinning biogas generation by additional substrates with high methane yield (e.g. fats, oils), which enables the installation of an AD facility of larger scale
- efficient utilization not only of the generated electricity but also of heat (e.g. local heat nets have been implemented at several sites) and of digestate (which is a particularly valuable fertilizer)

While economic benefit is difficult to be achieved, a zoo's two main predictable advantages from operating an AD plant are the positive ecological image and a reduced ecological footprint. Moreover it is an appealing element towards fulfilling the zoo's educational mission, especially if information on renewable energy generation in general and in particular on biogas production is made available to visitors in a devoted area.

D. Co-operatively owned Renewable Energy Facilities – A Model to be Adopted by Urban Lifestyle?

After several years of planning and research, which included giving up different scenarios due to failing financing schemes (similar to other biogas projects given up at different zoo sites), implementation of the AD plant at Toronto Zoo has resulted into the first co-operatively owned zoo biogas plant. Managed by the non-profit ZooShare Biogas Co-operative, shares are available to zoo members and citizens of Toronto [6].

Aside of environmental aspects and educational impact, the particular beauty of this project can be identified by recognizing the fact that it creates a unique element of identification through different effects:

- by addressing the benefit of community power
- through generation of renewable energy in an urban environment
- through provision of financial reward for zoo supporters
- by encouraging participation of people living in proximity

Transferability of such shining examples to other sites as well as to other renewable energy technologies is possible. Advances towards sustainability in an urban environment are achieved under many aspects with such projects, and include environmental, economic and social dimensions.

Active participation of the urban citizen within a context of high standards of technological and social infrastructure is one of the key characteristics of positively developing cities especially of the European style with their high degree of diversity, density and integrative capacity along different historical timelines and communities [7].

Although each renewable energy project is a unique challenge, what is predictable is that within the limited boundaries of a zoological site a facility which is well understandable and within reach to the general public will find high and in most cases positive attention and perception by a large variety of citizens. Such infrastructure is placed within the limited boundaries of a zoo, but it enriches urban life while at the same time it fulfils its aim of making a contribution to reduced environmental damage.

III. Conclusions and Outlook

Particular attractiveness of zoo AD projects and of renewable energy production at zoological sites in general results not only from the fact that they make a well definable contribution towards improving the energy balance of the individual site. The high potential to adapt and replicate the concept, the accompanying educational benefits, the placement within an urban environment, and the possibility to study a zoo within its defined boundaries as a model site are highly relevant factors.

Possible problems that occur during implementation of renewable energy projects originate from economic viability and technical challenges, and they might also be linked to acceptance of technologies and concepts due to specific perception by individuals. Transfer of knowledge, which will enable other sites to learn both from failed projects and from success stories will be one key element in advancing the topic. Intensified research is another prerequisite to reduce energy demands of zoos and in particular to make use of waste materials originating from zoo environments or botanical gardens.

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