Green stadiums:
as green as grass

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Summary

Sport stadiums around the world are not only used for the practice of sports, but also for shopping, concerts, museums, events and business meetings or conferences. The stadiums are multi-functional centers which attract a lot of people also when there is no event. Stadiums are getting larger and have more and more other functions, which increases the energy use and the environmental impact. Nowadays there are many possibilities to restrain the energy use with energy saving measures and renewable energy technologies.

In the EU-27 there are more than 4,000 stadiums. If all these stadiums use energy, generated by renewable energy technologies, it would save in total between 20 and 40 TWh/year generated by conventional fossil fuels. This is the equivalent of between 1 million and 2 million households in the Netherlands. Shifting to a more sustainable sport stadium sector in the EU-27 could have significant effects in the field of sustainable development.

The aim of this research is to create a general marginal cost-supply curve of energy saving and supply potentials of available energy saving measures and renewable energy technologies for sport stadiums, depending on the characteristics of the stadium. A case study is done to check the technical potential in 5 European stadiums.

The characteristics of an average stadium in North-West Europe are determined. The Green Arena, the average reference stadium in this research, has a capacity of around 46,000 persons and covers more than 50,000 m^2 of land. It has an electricity use of around 7,500 MWh/year and the heat/fuel use of almost 5,000 MWh/year, resulting in a total energy use of over 12,000 MWh/year. The functions which use the most electricity are the air handling unit and lighting. Regarding the heat functions, these are space heating and field heating. These are the target functions which are of most interest for energy efficiency improvements.

The available energy saving measures, to reduce the energy demand, are compiled in packages specific designed for a stadium. In this way the measures are adapted to the specific characteristics of the stadium. The measure packages, used in this research, consists of various measures (between 8-18) which address both the electricity and heat/fuel demand. These measure packages can save up to 4,000 MWh/year electricity and 800 MWh/year heat/fuel.

Also there are many renewable energy technologies available to use in stadiums for energy production. The technologies used in this research are wind turbines, urban wind turbines, solar PV, solar collectors and bio CHP plants. The energy supply potential of these technologies is very large. For wind energy it is more than 7,000 MWh/year electricity, for solar energy it is 570 MWh/year electricity and 2,250 MWh/year heat/fuel and for biomass it is 1,925 MWh/year electricity and 2,406 MWh/year heat/fuel.

In order to relate the energy saving measure packages and renewable energy technologies to the specific costs of saved final energy or generated final energy (€/MWh), a marginal cost-supply curve is constructed. The measure packages and renewable energy technologies all have specific costs between -100 €/MWh and -15€/MWh. The negative specific costs

indicates that all the options are economically attractive (including subsidies), which is beneficial for the deployment of these sustainable options.

A case study is done regarding 5 European stadiums to check the technical potential in practice. If a specific measure package and all renewable energy technologies are installed the technical potential of the stadiums is to reduce the electricity demand to zero and produce a surplus of electricity of between 1,500-5,000 MWh/year, depending of their own electricity use, and a heat/fuel demand of zero. This means that the stadiums can be self-sufficient and provide electricity for 400-2,000 households. The project has total investment costs of 7-14 million Euros, depending on the size of the stadium. Compared to the yearly revenues of the stadiums (up to 300 million Euros) it is a feasible project. Including subsidies, the Net Present Value of the projects are all positive. Hence, they are very economically attractive. The projects have Payback Periods of between 12-13 years.

At last a broad range of alternatives, to make a stadium energy neutral, are shown and analyzed. The energy scenarios ensure different ways to the same goal: energy neutrality. In order to realize an energy neutral stadium in the most economic way requires total investment costs of 8 million Euros. This scenario has a PBP of 15 years. A scenario where the bio-diesel CHP plant is excluded, because of limited space and still become energy neutral, will increase the investment costs to 11 million Euros and the PBP to 23 years. A scenario in which a stadium is electricity or heat/fuel neutral can be realized with 5 million Euros and a PBP of 15-17 years. This scenario is interesting when the electricity or heat/fuel prices are high. The scenarios all have positive NPV values (including subsidies). Hence they are economically very attractive.

The degree in which energy savings measures and renewable energy technologies can transform a stadium in an energy producing system is very high. The results of the research show positive NPV values (including subsidies) for the implementation of the measures and technologies. This indicates that transforming a stadium in a renewable energy producing system is economically attractive. It is time to take action and become a Green Stadium.

Preface

I would like to thank all the persons that have contributed to this master thesis. I am especially thankful to my supervisor Wina Graus for the feedback that kept me focused and structured during the research. Her feedback and accompaniment contributed a lot to the quality of the thesis. Another person that I would like to thank is my dad, A.F.J. Smulders. His feedback and evaluation of the thesis contributed also a lot to the quality of the thesis, but in greater extend to the stimulation of myself and writing of this thesis. At last I want to thank R. van Rossum and G. Noordermeer from Imtech, which were my supervisors at Imtech. Within very little time they both helped me very much with the data collection. It was not always how we want it, but still we achieved a lot. It was really a positive experience working together with all these people. The last thing to say is: enjoy reading my thesis and hopefully you think twice now when you visit a sport event.

Table of Content

1. Introduction

The goal of the first chapter is to create a view of the context in which way the research is done and in which way the research has been established. In paragraph 1.1 the background is described, which is followed by the problem definition and the aim of the research. Thereafter the main research question and the sub-questions are given in paragraph 1.3 and 1.4. At last, in 1.5, the reading guide is shown.

1.1 Background

The phenomenon *sport* is already known for thousands of years. Millions of people around the world practice sports. There are several sport events which are very popular, well attended and large. The most famous sport event in the world are the Olympic Games with 26 different Olympic sports. Other large sport events are the FIFA World Cup, the Super Bowl and the UEFA Champions League. These sport events get well over 100 million viewers (BBC, 2011). The best way to experience these impressive sport matches and the overwhelming atmosphere is to be physically present in the stadium. There is enough choice and place to let this dream come true, because there are over 11,000 stadiums around the world. They vary in size from small stadiums which can accommodate 5,000 spectators to mega-arenas that can accommodate more than 100,000 spectators. Some of these enormous stadiums can accommodate up to 250,000 spectators (World Stadiums, 2011).

The stadiums around the world are not only used for the practice of sports, but also for shopping, concerts, museums, events and business meetings or conferences. The stadiums are multi-functional centers which attract a lot of people also when there is no practice of sports (Imtech, 2011). The energy use of a stadium is dependent on the size and amount of functions it has. For instance, a medium-sized stadium which can accommodate around 55,000 spectators and has more functions then only sports, like a restaurant, business lounges, an event area and a museum, already has an energy use of more than 10,000 MWh each year (Imtech-Arena, 2011). The large energy consumption has a negative side-effect, which is of course a high energy bill through the rising energy prices, but especially the accompanied high CO_2 emissions (Dovi et al., 2009). Such a stadium can have an emission of 3,600 ton CO_2 each year. When the stadiums are getting bigger and have more and more other functions the energy use and accompanied CO_2 emissions will increase (Imtech, 2011).

Nowadays there are many possibilities to restrain the energy use and CO_2 emissions with energy saving measures and renewable energy technologies. The energy saving measures and renewable technologies are not specific for sport stadiums and can be used in, for instance, households as well. However, the scale and impact are much larger if the measures and technologies are implemented in sport stadiums. The implications, in terms of potentials, costs and feasibility, of transforming a stadium into a stadium which only uses and produces renewable energy are not well known because of the little research done about this subject.

Together with the immense popularity of sports, the great amount of sport stadiums and the increasing energy demand, the demand for research on the possibilities for energy saving measures and renewable energy solutions is present.

1.2 Problem definition and aim

One of the most challenging and controversial issues that the modern world is being asked to deal with, is the energy problem. Meeting the constantly increasing global energy demand, while addressing climate change as well as the rising energy prices, is a goal that requires maximum attention and active changes. The current global energy system is strongly dependent on fossil fuels which are scarce and produce CO_2 emissions when combusted, causing severe impacts on climate. For this reason there is now an emergent need for shifting to a more sustainable energy future (US Energy Information Administration 2011).

The larger the scale of this shift the greater the impact. In the EU-27 there are more than 4,000 stadiums (World Stadiums, 2011). If all these stadiums would have an average energy usage of 5-10 GWh/year, which is generated by renewable energy technologies, it would save in total between 20 and 40 TWh/year generated by conventional fossil fuels (Imtech-Arena, 2011). This is the equivalent of between 1 million and 2 million households in the Netherlands, which have an average energy use of 19.2 MWh/year (electricity + natural gas) (milieucentraal, 2012c). Shifting to a more sustainable sport stadium sector in the EU-27 could have significant effects in the field of sustainable development. Therefore the energy use of sport stadiums is an important topic to address and needs to be researched in order to gain more green sustainable stadiums. Hence, to ensure a reduction of the impact and carbon footprint on the global environment.

In order to work towards the optimization for the greening of stadiums the research is conducted in cooperation with Imtech. Imtech is a technical service provider and a big player in the field of green stadiums. Imtech already has a stadium named after themselves, the Imtech Arena in Germany. In this stadium they realized an energy reduction of 35% (3,273MWh) of the total energy usage of 11,450 MWh (Imtech-Arena, 2011). The gained expertise and knowledge on this topic can be used in other stadiums. For example the stadium of FC Groningen, de Euroborg. The goal of Imtech for this stadium is that it is energy and CO_2 neutral in 2013 and energy producing in 2020 (Draaijer et al., 2011).

Therefore the aim of this research is to create a general marginal cost-supply curve of energy saving and supply potentials of available energy saving measures and renewable energy technologies for sport stadiums, depending on the characteristics of the stadium. The curve can be used in a case-study to provide a range of measures and technologies which are tailor made for a specific stadium to transform the stadium into a renewable energy producing system. In this way the scientific findings can be used in real life cases to show if it is possible to create green stadiums with smaller energy demands which run on renewable energy.

1.3 Research question

The main question which will be answered in this research is:

"To what degree can energy saving measures and renewable energy technologies transform a stadium into an energy producing system"

1.4 Sub-questions

In order to answer this main research question several sub-questions are formulated:

- What is the energy consumption of a stadium and which factors are of influence?
- Which energy saving measures are available for stadiums and what is their energy savings potential?
- Which renewable energy technologies are available for stadiums and what is their energy supply potential?
- What are the specific costs of the energy saving measures and renewable energy technologies?

The sub-questions for the case study: 5 stadiums in the EU

- What is the technical potential for energy savings and supply in several European stadiums?
- What different alternatives are there to make the European stadiums energy neutral?

1.5 Reading guide

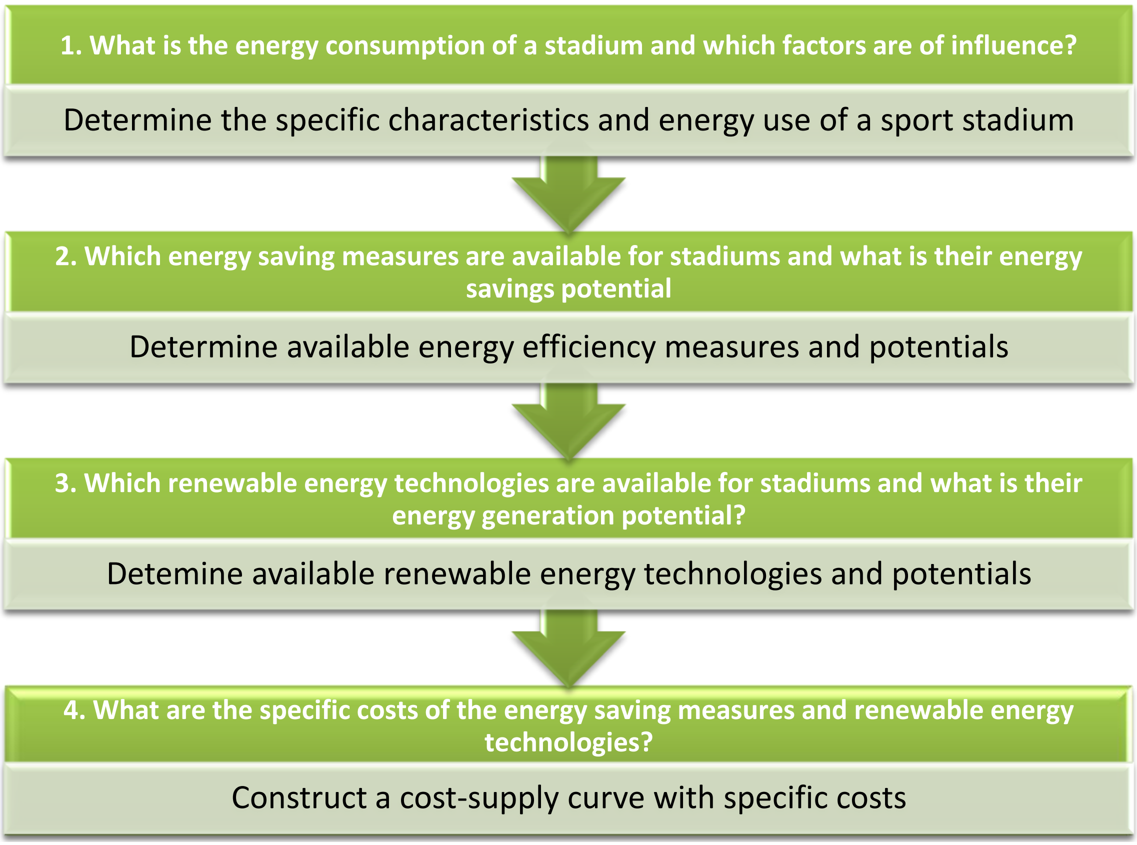
The structure of the research is as follows: in the next chapter (2) the methodology of the research is explained in detail. Step by step it will become clear in which way all the sub-questions are answered in order to obtain reliable results to answer the main research question.
In chapter 3 the energy consumption of a stadium is discussed. In chapter 4 and 5 the energy saving measures and renewable energy technologies are analyzed. Each of the measures and technologies are dealt with separately and the energy saving and supply potentials are calculated. In chapter 6 a marginal cost-supply curve is constructed of the energy saving measures and renewable energy technologies to create a clear overview of the specific costs of the measure packages and technologies. These chapters are the scientific part of the research and thereafter a case-study is done.
In chapter 7 the technical potential of several European stadiums is shown. In chapter 8 several energy scenarios are calculated to show the costs and energy supply of these scenarios. Finally, the discussion is given and the conclusion is drawn by means of answering the main research question.

2. Methodology

In this chapter the methodology of the research is explained in detail. First, in paragraph 2.1, an overview of all the different steps is given to get a clear picture about the working method of the research. The paragraphs 2.2 - 2.7 are all in line with the sub-questions. In paragraph 2.2 the required data of stadiums and the division of the energy use by functions is shown. In paragraph 2.3 and 2.4 the required data for the energy saving measures and renewable energy technologies to calculate their potential is enumerated. In paragraph 2.5 the calculation method of the marginal cost-supply curve is shown. The paragraphs 2.6 and 2.7 are both focused on case studies. In 2.6 there is a description of the economical and technical potential and in 2.7 there are several energy packages described. At last in 2.8 the data collection method is shown.

2.1 Overview: steps of the research

The research is conducted in 6 steps following the sub-questions and making use of several research methods. In this way the research is structured and the sub-questions are answered. The 6 main steps are:



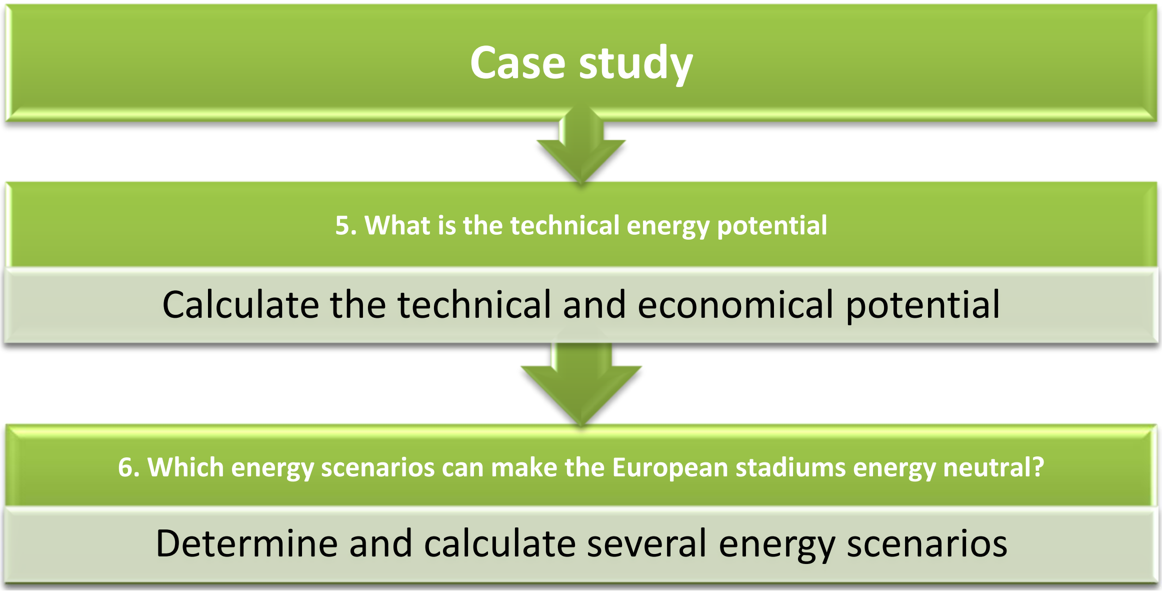


Figure 1. Steps of the research

2.2 Step 1: Specific characteristics and energy use

In the first step the specific characteristics and the energy use of a sport stadium are determined. The characteristics of multiple sport stadiums are determined to get a stadium which is an average stadium that can be used as a reference stadium. This stadium will be used to analyze and calculate the potentials of the energy saving measures and renewable energy technologies in addition to the specific costs. The data required for the specific characteristics of the reference stadium include the size of the stadium which is the total footprint of the building (m^2), the size of the roof (m^2) and the energy use (electricity: MWh or heat/fuels used: GJ or MWh). This data is required, because the impact of the energy saving measures and the size of the renewable energy technologies are dependent on the size of the stadium.

Table 1. required data characteristics sport stadium

Data required for specific characteristics of a sport stadium	
Size of the stadium	m^2
Size of the roof	m^2
Energy use - electricity	MWh/year
Energy use - heat/fuel	GJ or MWh/year

In order to determine energy savings and energy supply potentials in stadiums it is necessary to get an idea about what type of functions the energy is used for. Therefore the energy use will be broken down into function areas. The two main areas are “stadium” and “other”. These two main functions areas are broken down into two types of energy use: electricity and heat/fuel. The functions for electricity are: lighting, pumps, appliances, air conditioning and other (Sleegers, 2009) (ECN, 1999). The function areas for heat/fuel are: (field) heating, hot water and other. Each function will have a certain amount of the total energy use. The breakdown will clarify the areas which have the largest energy use (i.e. have the greatest potential for energy savings). The breakdown is visualized in the next figure.

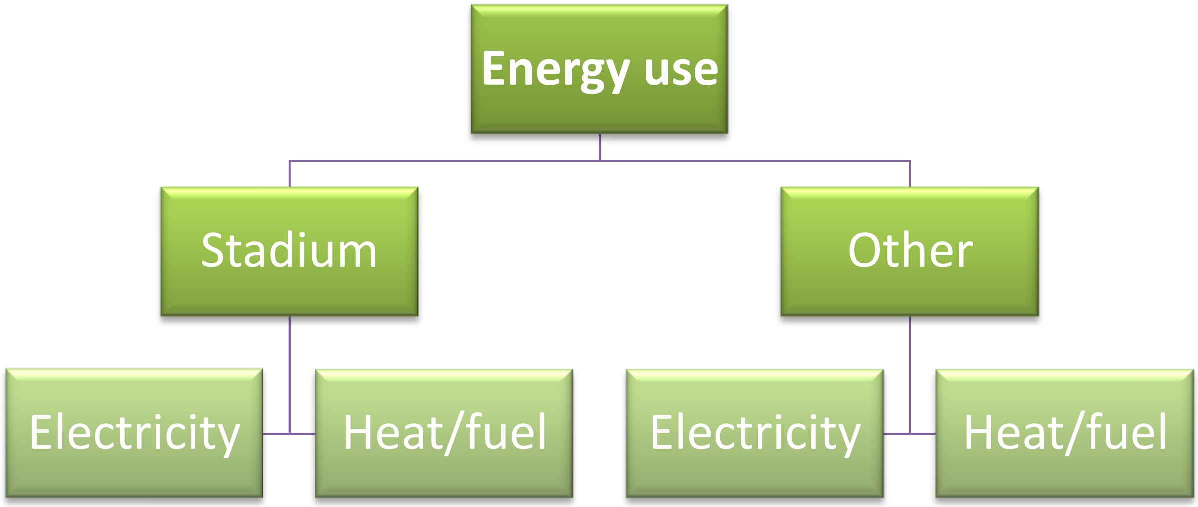


Figure 2. Areas of energy use

The total energy use of the stadium is divided into 2 main areas: 'stadium' and 'other'. The area 'stadium' includes the playing field, the field lighting when it is dark and lighting for irradiation of the grass. The area 'other' includes all other functions as lighting in offices, heating, air-conditioning, appliances used in shops and dining etc.

Also important to determine is the energy use of a stadium during a whole year. In this way seasonal fluctuations in heat demand, the base load electricity demand and peak demands can be analyzed. This is done in order to find out where the highest potential for energy savings are i.e. the area in which the most energy saving measures can be implemented and the most renewable energy can be used. The area with the highest potential is the area on which the focus will be in this research.

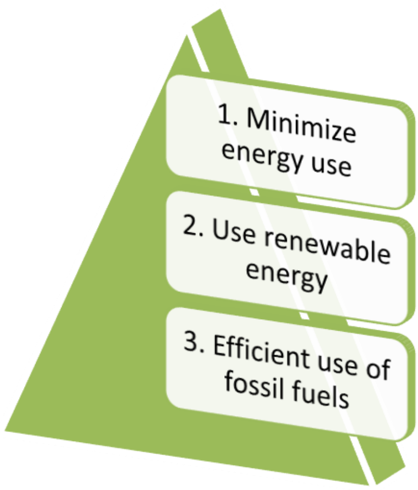


Figure 3. Trias Energetica

In order to realize the change to a renewable energy producing stadium two ways are taken into account: energy saving measures and renewable energy technologies. According to the Trias Energetica (MVROM, 2009), the energy use must first be reduced by the implementation of energy saving measures. Thereafter the remaining part of the energy use of the stadium (and the additional part) must be, as much as possible, covered by the use of renewable energy technologies. At last the remaining part of the energy use is covered by efficient use of fossil fuels. In this way energy is saved first, secondly renewable energy is supplied and at last the remaining part is covered with conventional fuels. Hence, by dealing with the energy use in the structured way of the Trias Energetica it ensures a maximum share of renewable energy of the total energy use. The energy supply will be used for both electricity and heat. In this way the two different paths, energy savings and energy supply, don't compete with each other.

2.3 Step 2: Energy saving measures

In the second step the available energy saving measures within stadiums are reviewed and analyzed to create a list of the most important measures, based on the breakdown in step 1, to be used in a stadium to realize energy savings. Energy saving is the strive to reach a certain or maximum output with a minimum of input e.g. reaching the same goal but using less energy. The reduction of the energy usage can be technological and non-technological such as a managerial or organizational change (WEC, 2012). In this research the focus is on technological improvement. The non-technological improvements are not taken into account. The research focuses on measures such as an energy saving improvement thanks to the use of LED lighting, which uses 85% less energy to generate the same amount of light, instead of traditional lighting. A change in management or behavior is not included in the research, because it is a research done about the technical potential of stadiums.
The data required for energy saving measures include energy savings (MWh or % improvement compared to reference technology), the costs of the initial investment (Euros), the costs for operation & maintenance (O&M, Euros) and the lifetime (years).

Table 2. Required data energy saving measures

Data required for energy saving measures	
Energy savings or energy improvement	MWh or % improvement
Costs (initial investment)	Euros, €
Costs (Operation & Maintenance)	Euros, €
Lifetime	Years

2.4 Step 3: Renewable energy technologies

In the third step the available renewable energy technologies within stadiums are reviewed and analyzed to create a list of the most important and frequently used technologies to use in a stadium to transform it into an energy producing system. Renewable energy technologies are technologies which use renewable energy sources to generate energy. The renewable energy sources are solar, geophysical or biological sources that are supplemented by natural processes at a rate that equals or exceeds its rate of use (IPCC, 2011). The energy comes from continuing flows of energy occurring in the natural environment, which include: solar power, wind power, hydro power, tide and wave energy, geothermal energy and energy from biomass (IPCC, 2011).
The data required for renewable energy technologies include energy supply (MWh), the costs of the initial investment (Euros), the costs for operation & maintenance (O&M, Euros) and the lifetime (years).

Table 3. Required data for renewable energy technologies

Data required for energy saving measures	
Energy supply	MWh
Costs (initial investment)	Euros, €
Costs (Operation & Maintenance)	Euros, €
Lifetime	Years

2.5 Step 4: Marginal Cost-Supply curve

In the fourth step a marginal cost-supply curve is made of the energy saving measures and renewable technologies list, prepared in step 2 and 3. In this way the energy saving measures and renewable energy technologies are ranked by their specific costs of saved final energy in €/MWh (Blok, 2007). The choice for final energy is made, because the stadium is using final energy. If the stadium has a surplus of produced electricity it is transported to surrounding households as final energy.

In order to calculate the specific costs of saved final energy (C_{spec}) the next equation is used:

$$C_{spec} = \frac{\alpha \,.\, I + C - B}{\Delta E}$$

$$\alpha = \frac{r}{1-(1+r)^{-L}}$$

Where:
α. I = annual capital costs (α = the capital recovery factor, I = Initial investment)
C = Operation & Maintenance costs
B = annual benefits
ΔE = annual saved final energy
r = discount rate (6%, social perspective)
L = the lifetime of the measure/technology

The graph will have two axis, on the vertical axe the specific costs (€/MWh) is plotted and on the horizontal axe the potential (saved final energy) is plotted. By doing this the measure/technology with the lowest specific costs is shown on the left and the most expensive measure/technology is shown on the right. The curve gives a clear overview of the specific costs and the saved final energy potential of the different options which can be used to transform a stadium into an energy producing system (Blok, 2007).

The marginal cost-supply curve is a convenient way to represent the technical potential of the measures and technologies (Blok, 2007). The technical potential is “the contribution that could be made by the technologies in a certain (future) year”. The part of the technical potential that is economically attractive from a social perspective are the options which are below the zero-line i.e. - €/MWh (Blok, 2007). The technical potential is determined with respect to a frozen-technology situation. The frozen-technology situation is chosen in the base year 2010. The technical potential is likely to increase over the years as a result of continuous technological developments which increases the savings and lower the costs. In order to calculate the technical potential the time span needs to be determined, because it will clarify which measures and technologies can be taken into account for the research. The goal is to get an idea about the potentials and costs of the energy saving measures and renewable energy technologies for a reference stadium in 2020. The selected energy saving measures and renewable technologies that are or will be available in this time span are included in the research.

Case study: 5 stadiums in the EU

2.6 Step 5: Technical potential

In the fifth step the case of the 5 stadiums in the EU is dealt with. Making use of the marginal cost-supply curve made in step 4, the technical potential of the stadiums is calculated. The potential is dependent on the specific characteristics of the stadium in comparison to the reference stadium determined in step 1. In order to calculate the energy potential the reference situation needs to be clear, because it is determined with respect to this situation. Next to the technical potential the following elements are calculated:

- *Number of households,* which are the number of household that can be provided with the surplus of electricity produced by the stadium. The surplus of electricity is divided by the average electricity use of a household (= 3,500 kWh) (Milieucentraal, 2012d). Installing renewable energy technologies can result in a surplus of electricity. This is beneficial, because the electricity can be sent back to the grid and sold again. So the more numbers of households which can be provided with this electricity the lower the payback time.
- *The total investment costs*, which are the initial costs of the specific measure package + the initial costs of all the renewable energy technologies. Afterwards the total investment costs are analyzed and compared to the total revenues of the stadium in order to see if the total investment costs of the project are realistic and feasible.
- *The Net Present Value (NPV),* which is the present value of the project. In order to calculate the NPV, the next equation is used:

$$\mathrm{NPV} = -\mathrm{I}\frac{\mathrm{B}-\mathrm{C}}{\alpha} \qquad \alpha = \frac{r}{1-(1+r)^{-L}}$$

Where:
I = initial investment
B = annual benefits
C = annual costs
α = capital recovery factor
r = discount rate (6%, social perspective)
L = the lifetime of the project

The NPV is calculated to see the current value of the project. A project is considered to be attractive if the NPV is positive (Blok, 2007). So the project is highly dependent on the NPV.

- *The Payback Period (PBP),* The PBP is an important figure for decision-making people, because this shows black on white how much time is required to pay back the total investment costs with the benefits of the project. The next equation is used:

$$\mathrm{PBP} = \frac{\mathrm{I}}{\mathrm{B} - \mathrm{C}}$$

Where:
I = the initial investment
B= benefits
C = annual costs

The benefits are the energy savings (electricity and heat) + renewable energy production for own use (electricity and heat) + renewable energy surplus (electricity) all multiplied by the electricity and gas price. The annual costs are the O&M costs. Afterwards the total investment costs is divided by this number which gives the payback period in years.

2.7 Step 6: Energy scenarios

In the sixth step, several energy scenarios are set together and calculated to show different outcomes to make a stadium energy neutral in terms of different used technologies, energy supply and costs. Energy neutral is: “A project is energy neutral if there is no annual net import of fossil or nuclear fuel necessary from outside the system boundary to the building to establish, operate and break down. This means that the energy use within the project is equal to the amount of sustainable energy within the project boundary generated” (Agentschap, 2010). In this way various potential alternatives can be analyzed to make a stadium energy neutral. Hence, the use of scenarios can show a broader range of alternatives to make a stadium energy neutral which creates more complete solutions for all different kinds of stadiums e.g. when there is not much space available or when the costs need to be minimized.

2.8 Data collection

The required data for the specific characteristics of a stadium and the energy use is collected at Imtech. They have much experience related to transforming and adapting stadiums into more green stadiums. Also there are energy researches available which shows the specific division of energy use by functions. This ensures a clear breakdown of the energy use within a stadium.

The required data for the energy saving measures and renewable energy technologies is partly collected at Imtech as they have experience with energy saving measures and renewable energy technologies in stadiums. However, scientific articles, information from websites and organizations are also used to gain thoughts/ideas including data about usable energy saving measures and renewable energy technologies. Other important sources are the study of Ecofys: Sectoral Emission Reduction Potentials and Economic Costs for Climate Change (SERPEC-CC) (Ecofys, 2009), the study: Energy technology perspectives 2010 from the International Energy agency (IEA, 2010) and the study of the European Commission: Renewable energy technologies (EC, 2007).

3. Energy consumption of a stadium

The specific characteristics and the energy use of a sport stadium are determined to analyze and calculate the potentials of the energy saving measures and renewable energy technologies. In order to do this (in paragraph 3.1) several characteristics of multiple sport stadiums are determined to create a stadium, which is an average stadium, which can be used as a reference stadium. In paragraph 3.2 the division of energy use by functions is shown of the stadium including the other functions of the stadium. Also the energy use during the year is shown and analyzed. At last in paragraph 3.3 the conclusion of the chapter is given.

3.1 The Green Arena

The selected stadiums are listed in Table 4. These stadiums are chosen, because Imtech has specific and detailed information about the stadiums and energy use. The stadiums are already or will be addressed by Imtech to decrease the energy use. However, more important, the list contains stadiums from all different kind of sizes which ensure a good representation of different types of stadiums. The stadiums with a capacity of under the 20,000 persons are left out, because these stadiums (often) do not have a roof. The energy use is not that high for great energy saving potentials and the multi-functionality is not present.

Table 4. Stadiums (Sleegers, 2009) (Horstmann, 2010)(Merz, 2011)

Stadium	Country	Capacity	Roof	footprint	Energy use (MWh/year)		
		X 1000	m^2 (x 1000)		Electricity	Heat/fuel	total
Imtech Arena	Germany	57	35	50	0.094/m^2	0.135/m^2	11450
Euroborg	Netherlands	22	13	18.4	0.114/m^2	0.094m^2	3822
Commerzbank	Germany	52	34	39.9	0.138/m^2	0.126/m^2	10515
Allianz Arena	Germany	69	38	73.9	0.179/m^2	0.114/m^2	21741

The characteristics of all these stadiums are used to determine a reference stadium which will be called "The Green Arena". All the calculations are done on the basis of the characteristics of the Green Arena. All the figures of the Green Arena are averages of the selected stadiums. All the selected stadiums which are taken into account are not shown in Table 4, only the ones which will be dealt with in the rest of the research. In this way a realistic representation of an average stadium is given. The characteristics of the Green Arena are shown in Table 5.

Table 5. Figures of the Green Arena

The Green Arena	
Capacity	46,300
Size of the stadium	53,250 m^2
Size of the roof	33,120 m^2
Energy use - electricity	0.140 MWh/m^2/year
Energy use - heat/fuel	0.090 MWh/m^2/year
Energy use - total	12,265 MWh/year

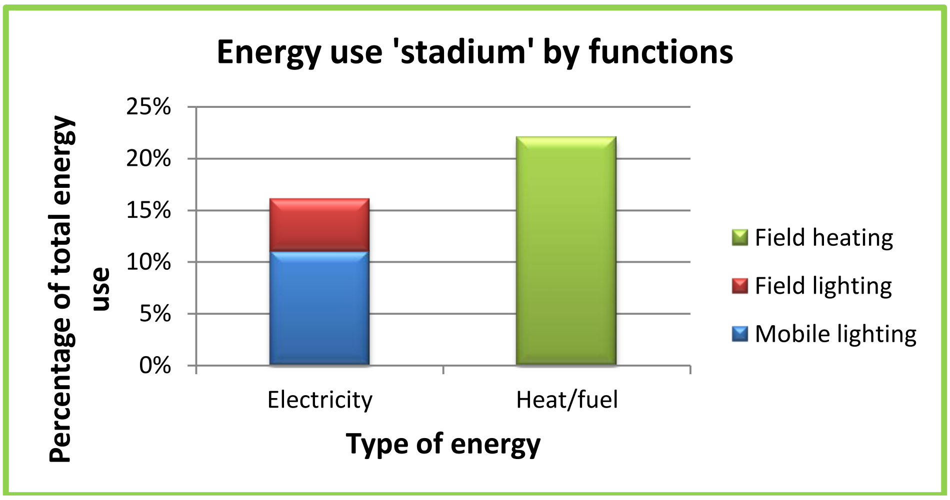
3.2 Energy use and functions

In order to determine energy savings and energy supply potentials in stadiums it is necessary to get an idea about what type of functions the energy is used for. The energy use is divided into 2 main areas: stadium and other. Thereafter the energy use will be broken down into 2 types of energy use: electricity and heat/fuel. Each of these types of energy use will have multiple applications.

The breakdown into main areas, energy type per main area and the applications of the energy can be done for each stadium in the world. However, the percentages and application of energy use shown in the figures within this paragraph are from an energy research specific for the Euroborg stadium (Sleegers, 2009). The Euroborg is a good reference stadium, because it is a typical multifunctional stadium. The whole system consists of the standard seats, playing field, dressing rooms, shops, parking lot etc., but also a museum, a cinema, multiple conference rooms, an event calendar and restaurants. The energy use breakdown of stadiums around the world is almost the same as given by Dietrich et al. (2011). Also the energy use breakdown can be compared to a large extent to commercial buildings (Dietrich et al., 2011). The breakdown of the energy use by functions in a stadium is also dependent on the climate where it is located. The Green Arena will have the location North-West Europe.

3.2.1 The energy use of the stadium

The area "stadium" only includes the sports area (the playing field), because the seats in a stadium are not heated hence this will not require any energy. The playing field is heated, the field is lighted (when dark) and the field is irradiated to ensure the growth of the grass. The percentages of the functions of the stadium area are shown in Graph 1.



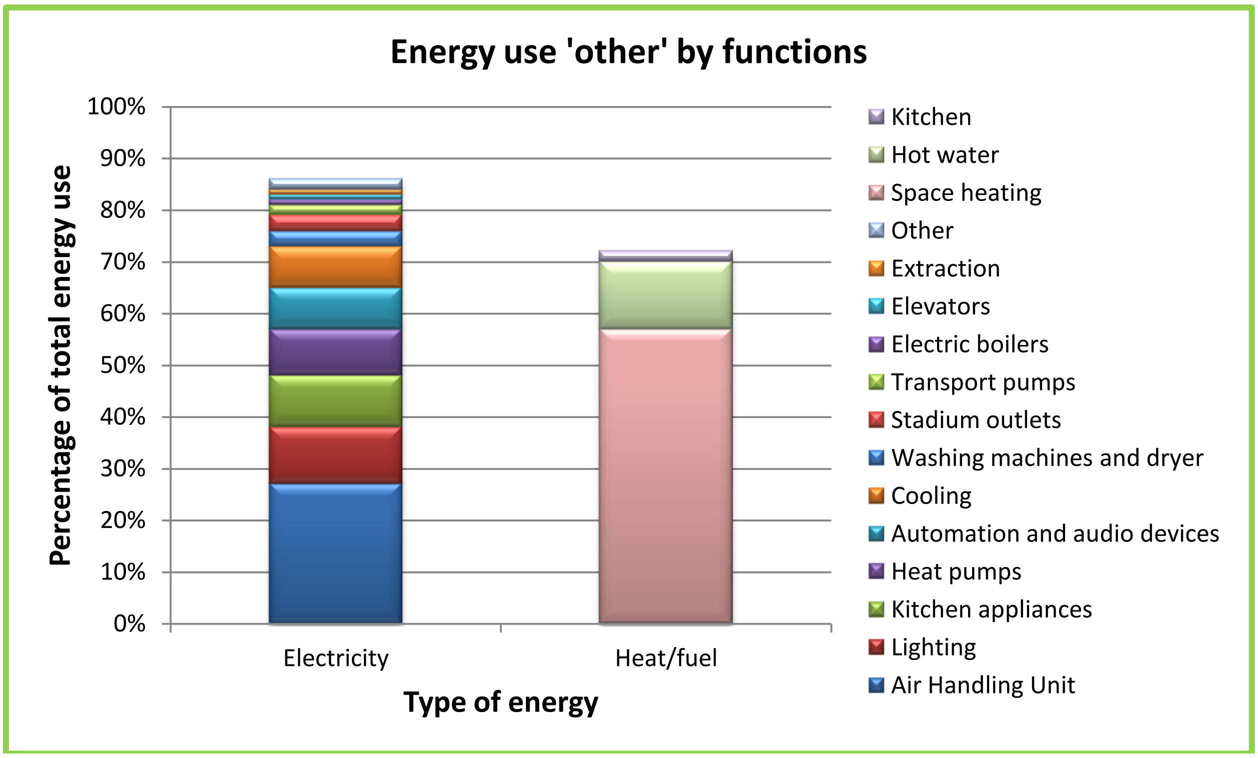
Graph 1. Energy use 'stadium' by area (Sleegers, 2009).

The energy use of the stadium (the Euroborg) is only responsible for 16% of the electricity use and 22% of the heat/fuel use in a sport complex. The electricity use can be divided into 2 functions: the mobile lighting for the growth of the grass which accounts for 11% and the field lighting accounts for 5%. The energy use of the stadium is responsible for 22% of the total heat/fuel use which is completely used for the under soil heating of the field (Sleegers, 2009). The ‘stadium’ electricity & heat/fuel use is more or less responsible for 20% of the total energy use of a sport complex.

The largest function types for energy efficiency improvement are for electricity; the mobile lighting and for heat/fuel; the under soil field heating. These areas use the most energy and therefore these areas are of most interest.

3.2.2 The energy use of other functions

The area “other” includes offices, shops, museums, dining areas, elevators, video/audio devices, air-conditioning e.g. all other different functions which are used outside the playing field. The percentages of the functions of the other area are shown in Graph 2.



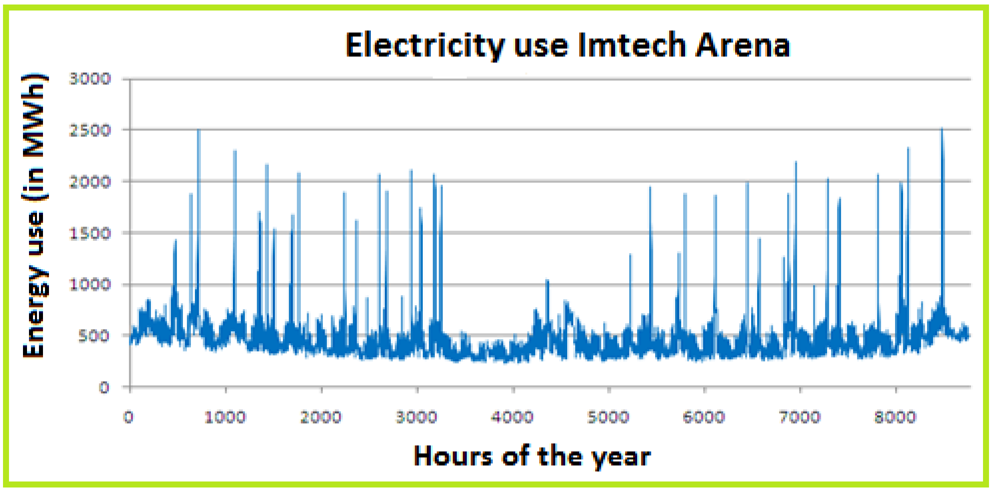
Graph 2. Energy use ‘other functions’ by area (Sleegers, 2009).

The energy use of the other functions of a stadium are responsible for 84% of the electricity use and 78% of the heat/fuel use. The electricity use can be divided in many functions as it is used for many different applications. The largest electricity users are the air-conditioning, lighting, kitchen appliances, heat/fuel pumps, automation and audio devices and cooling. These functions account for almost 75% of the electricity use of the other functions. The heat/fuel is only used for 3 functions: space heating, hot water and kitchen. The function space heating accounts for almost 60% of the total heat/fuel use. The hot water function for a much smaller piece, only 13% (Sleegers, 2009). The ‘other functions’ electricity & heat/fuel are more or less responsible for 80% of the total energy use of a sport complex.

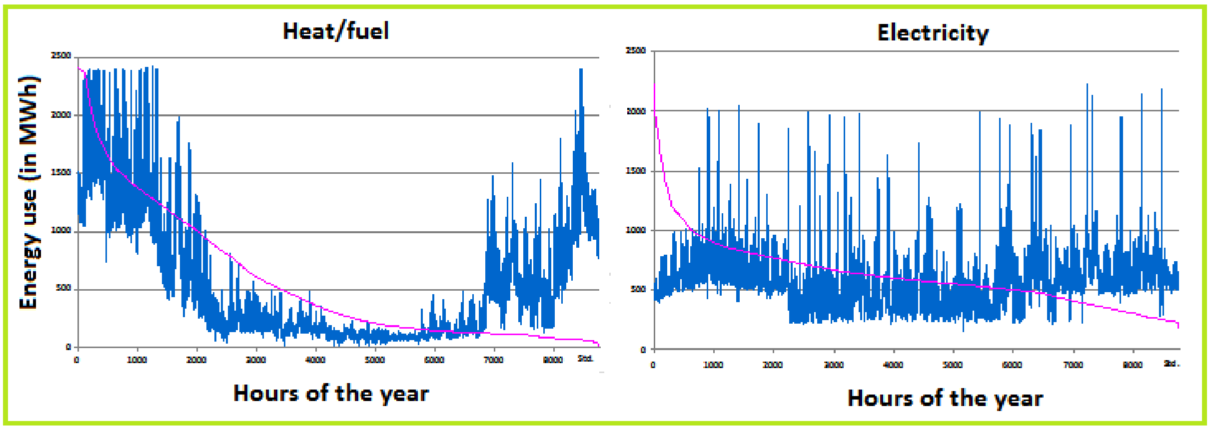
The largest function types for energy efficiency improvement are for electricity; the air-conditioning, lighting, kitchen appliances, automation and audio devices and cooling. For heat/fuel; space heating and hot water. These areas use the most energy and therefore these areas are of most interest.

3.2.3 The energy use during the year

The energy use of a stadium during a whole year is an important aspect to analyse in order to determine the area with the highest potential for energy savings. Graph 3 shows the electricity use of the Imtech Arena during 2009. Graph 4 shows the heat/fuel and electricity use of the Commerzbank Arena in 2009 (Horstmann, 2010).



Graph 3. Electricity use Imtech Arena



Graph 4. Heat/fuel and electricity use Commerzbank Arena

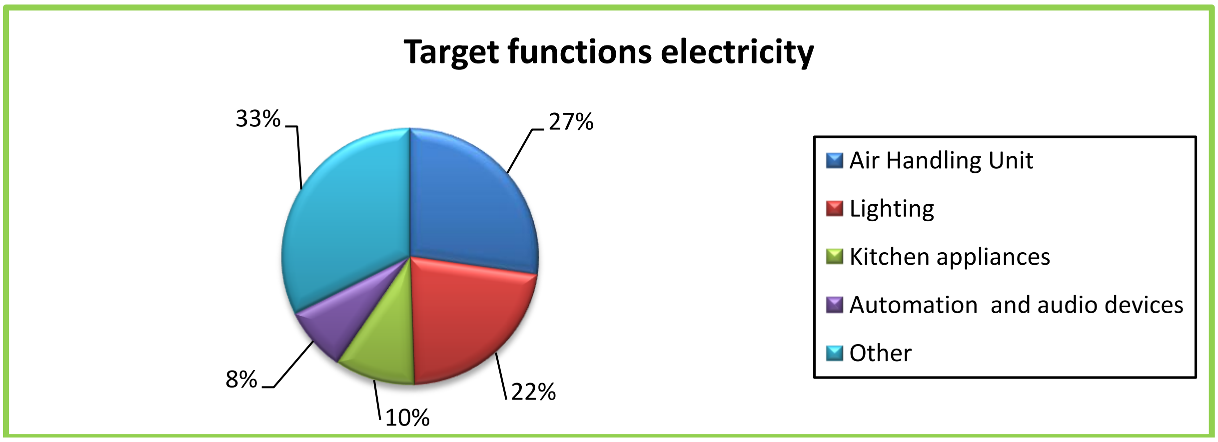
In the heat/fuel graph of the Commerzbank arena it can be seen that the heat demand follows the seasonal fluctuations i.e. a high heat demand in winter months (hours 0-2,000 and 7,000-8,760) and a low heat demand during summer months (hours 2,000-7,000). However, in the electricity graph of the Imtech Arena and the Commerzbank Arena these seasonal fluctuations cannot be seen. The electricity demand remains almost steady during the year except during events which causes these peaks. Hence, the largest part of the electricity use is a kind of a base load electricity use and the other smaller part are peak demands during events. The number of events can almost be read from the graph. Concluding from these graphs it can be said that 80% of the energy use is during non-events and 20% is during events (Horstmann, 2010) (Merz, 2011).

3.3 Conclusion

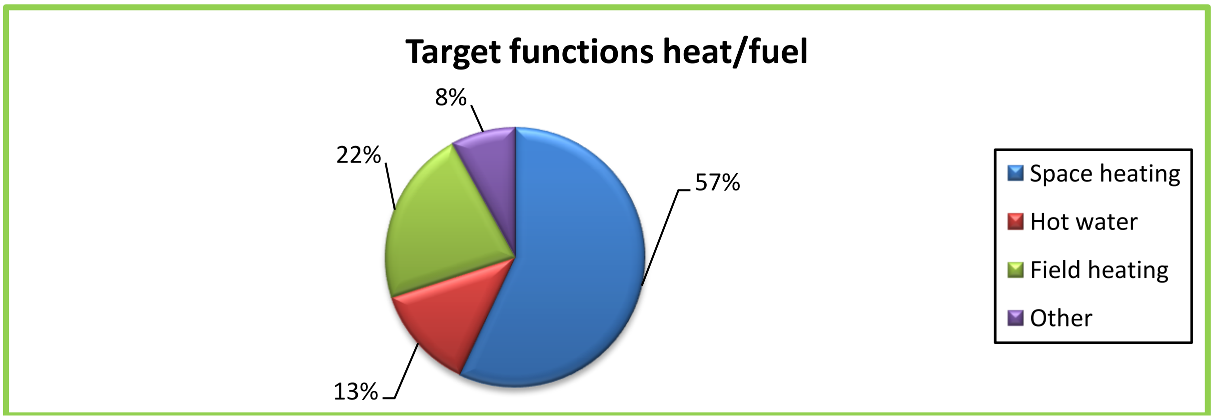
The characteristics of the reference stadium are determined and used for calculations done in the research. The Green Arena is a stadium with a capacity of over 46,000 persons and covers more than 50,000 m^2 of land. The electricity use is around 7,500 MWh/year and the heat/fuel use is almost 5,000 MWh/year, resulting in a total energy use of over 12,000 MWh/year. 20% of this energy is used during events and 80% when no events occur.

The breakdown of the energy use by functions show the target functions which are of most interest. In the main area 'stadium' the electricity use accounts for 15% of the energy use and the heat/fuel use accounts for 22%. Both the percentages are relatively low in comparison to the energy use of the 'other functions'. In which the electricity accounts for 85% of the energy use and the heat/fuel for 78% of the energy use. Although these percentages can vary between different kinds and sizes of stadiums. At the end it can be said that the stadium is responsible for 20% of the energy use and the other functions are responsible for 80% of the energy use.

The largest function types for energy efficiency improvement are shown in the Pie-charts 1 and 2. The four largest electricity consumers cover 67% of the total electricity use. The three largest heat/fuel consumers cover 92% of the total heat/fuel use. Hence, these are the areas on which the focus will be to reduce the energy consumption.



Pie-chart 1. Target functions electricity



Pie-chart 2. Target functions heat/fuel

4. Energy Saving Measures

The available energy saving measures within stadiums are reviewed and analyzed to create a list of most important and frequently used measures in stadiums. In paragraph 4.1 each of the measures is dealt with separately for further detail. A description of the measure is given and the most important figures are shown as well as the energy saving potential per year. In paragraph 4.2 an overview of the available energy saving measures and their potentials per year is shown to show a clear overview. In 4.3 the distribution of the measures is shown and in 4.4 the change in energy consumption before and after implementation is calculated. At last in paragraph 4.5 the conclusion of the chapter is given.

4.1 Measures

The energy saving measures are combined in packages. In this way a whole measure package can be implemented in a stadium. Due to the uniqueness of each stadium in terms of technologies used, the difference in size and energy consumption the measure packages are scaled to show the potential energy savings related to the Green Arena. This is done by:

$$energy\ saving\ measure\ (scaled) = \frac{\text{energy saving measure}}{\text{energy use specific stadium/energy use Green Arena}}$$

Where energy is electricity if the measure saves electricity and energy is heat/fuel when the measure saves heat/fuel. In this way it is more specific for the kind of energy and not for the total energy use.

The packages are calculated and compiled by Imtech. Package 1 is originally calculated for the Imtech Arena, package 2 is originally calculated for the Commerzbank Arena and package 3 is originally calculated for the Allianz Arena. The measures in the Imtech-Arena, Commerzbank Arena and Allianz Arena are scaled to the Green Arena. The energy savings of the measures per package can be added together. However, different packages cannot be implemented in the same stadium because of the overlap between several measures. The measures are easy applicable and save a lot of energy. However they are not the maximum saving potential. Next to these measures additional measures can be installed to decrease the energy consumption of a stadium.

4.1.1 Package 1: Imtech Arena

The energy saving measure package 1 consists of 8 measures which can decrease the energy use of a stadium (Horstmann, 2010). From top to bottom the measures are:

- *Combined heat supply with absorption chiller* - the heat supply and absorption chiller works independently. The measure consists of connecting the systems with each other. In this way the supplied heat can also be used for cooling for instance refrigerators or air-conditioning. The measure can save 107 MWh/year = -2.2% of the stadium total heat/fuel use.
- *Heat recovery in HVAC systems* - the HVAC system does not make use of any recovery system. The measure consists of a recovery ventilation system using a heat

exchanger which ensures a counter current heat exchange between the inbound and outbound air flow. This decreases heating/cooling energy, improves climate control and provides fresh air. The measure can save of 227 MWh/year = -4.8% of the stadium total heat/fuel use.

- *Under floor heat control* - the floor heat does not make use of any control system. The measure consists of a control system with room presence sensors. In this way the floor heating is controlled and only used when someone is present. The measure can save 142 MWH/year = -3.0% of the stadium total heat/fuel use.
- *Optimization of under soil field heating* - only one heat circuit is present. The measure consists of dividing the under soil field heat system into 4 different heat areas. In this way the distance travelled is much shorter which ensures less heat loss. The measure can save 71 MWh/year = -1.5% of the stadium total heat/fuel use.
- *Optimization of natural air exchange* - through bad air change a cold spot can be formed in the middle of the stadium. The measure consists of optimization of the natural air exchange in the stadium. This ensures a warmer air flow inside the stadium and therefore less use of the soil heating system. The measure can save 334 MWh/year = -7.0% of the stadium total heat/fuel use.
- RAUM-talk - no integrated control system is in use. The measure consists of installation of a system which ensures an intelligent adjustment of current consumption to target consumption. In the boxes of a stadium, RAUM-talk can ensure an energy savings of 317 MWh/year. RAUM-talk can save 2,833 MWh/year in the Arena, building management system and the EIB Bus (a system in which electrical components are interconnected and can influence each other). Respectively, these are energy savings of -4.2% and -37.8% of the stadium total electricity use.
- *Lighting* - a stadium can retrofit the lighting department which ensures a electricity savings of 54%. The measure can save 891 MWh. (Dietrich et al., 2011).

The total amount of **saved energy with measure package 1 is 4,922 MWh/year**. The measures save both electricity and heat/fuel. The electricity demand decreases with 54.0% respectively 4,041 MWh. The heat/fuel demand decreases with 18.4% respectively 881 MWh. The total investment for **energy saving package 1 is 1,896,050€** (Horstmann, 2010)(Merz, 2011).

4.1.2 Package 2: Commerzbank Arena

The energy saving measure package 2 consist of 10 measures which can decrease the energy use of a stadium (Horstmann, 2010). From top to bottom the measures are:

- *Measures in the boxes* - boxes without variable air volume control valve. Part load is not possible. The measure consists of replacement of the constant air volume control valve to variable air volume control valve, additional frequency converter and installation of motion, presence detector and air quality sensors. The measure can save 95 MWh/year = -2.0% of the stadium total heat/fuel use
- *Hydraulic commissioning of the heating system* - no commissioning of the heat system. The measure consists of installation of additional heat pumps to give more pressure on the flow distributor and commissioning the flow rate of the heating and

cooling system. The measure can save 191 MWh/year = -4.0% of the stadium total heat/fuel use

- *Reduce the air flow rate* - all Air Handling Units (AHU) are without frequency converter. High flow rates in the technical operating rooms and AHU in the kitchen are continuous running. The measure consists of installing a frequency converter, reduce the airflow rate, installation of motion and presence detectors, recirculation air operation. The AHU must work in part load. The measure can save 204 MWh/year = -4.3 % of the stadium total heat/fuel use.
- *Optimization of soil heating* - only one heating circuit is present and the heat exchangers of the soil heating system are connected with the flow pipe (80°C). The measures consists of splitting the heating circuit in four different heating circuits and switching the supply of the soil heating from the flow to the return pipe (50°C). The measure can save 381 MWh/year = -8.0% of the stadium total heat/fuel use.
- *Measures in the basement garage* - all basement garage areas are operating all year long and 100% of the lighting is in operation at the gateways during the year. The measure consists of 1/3 cut off of the electrical lighting in all parking areas, blocking of several parking areas and switching off the electric lighting at the gateways which are not used. The measure can save 144.5 MWh/year = -1.8% of the stadium total electricity use
- *Switch off consumers in the kiosk* - in the kiosks not all consumers are switched off. The measure consists of switching off the consumers during the non event time and control the switch off. The measure can save 352 MWh/year = -4.7% of the stadium total electricity use.
- *Upgrade Building Management System (BMS)* - the heat/fueling pumps and AHU are not controlled by a integrated requirement system. The measure consists of switching of the pumps controlled by the BMS and switching off or part load use the AHU related to the requirement. The measure can save 109 MWh/year = -1.5 of the stadium total electricity use.
- *Reduce the electrical base load* - electrical base load in the arena over 450kW and offices are heated and chilled by split units. The measure consists of switching of the consumers, which are not needed (Standard Load 200kW) and installation of water based radiators for offices. The measure can save 476 MWh/year = -6.4% of the stadium total electricity use.
- *Miscellaneous Measures* - Inject exhaust air in the basement garage, counter for operating time for pumps and motors, reduce the split units level in floors and rooms (1/3 switching), motion sensors for floors and staircases. All these smaller, but helpful measure can save 82 MWh/year = -1.1% of the stadium total electricity use.
- *Lighting* - a stadium can retrofit the lighting department which ensures an electricity savings of 54%. The measure can save 891 MWh/year. (Dietrich et al., 2011).

The total amount of **saved energy with measure package 2 is 2,926.5 MWh/year**. The measures save both electricity and heat/fuel. The electricity demand decreases with 27.5% respectively 2,055.5 MWh. The heat/fuel demand decreases with 18.2% respectively 871 MWh. The total investment for **energy saving package 2 is 1,593,600€** (Horstmann, 2010).

4.1.3 Package 3: Allianz Arena

The energy saving measure package 3 consist of 18 measures which can decrease the energy use of a stadium (Merz,2011). From top to bottom the measures are:

- *Air quality sensors* - old or none air quality sensors are present. The measure consist of upgrading the sensors for CO^2 concentration, temperature and humidity in the stadium areas in order to optimize the required continuous adjustments. The measure can save 84 MWh/year = -1.8% of the stadium total heat/fuel use and 43 MWh/year = - 0.6% of the stadium total electricity use.
- *Exhaust gas heat exchanger* - the measure consists of placing a second exhaust gas heat exchanger next to the boiler. The measure ensures a higher saving of the boiler and the heat can be reused for other purposes. The measure can save 91 MWh/year = -1.9% of the stadium total heat/fuel use.
- *Integration of the field heating in the network* - the measure consists of connecting the field heating to the whole heating network of the stadium. The condensing properties of the boiler are increased. The measure can save 72 MWh/year = -1.5% of the stadium total heat/fuel use.
- *Night setback and adaptation of the heating curve* - the measure consists of following an optimized heating curve when the room temperatures need to be heated from 17 to 20 degrees and during night times. The measure can save 91 MWh/year = -1.9% of the stadium total heat/fuel use.
- *Boiler control optimization* - the measure consists of integrating the control system of the boilers and install a minimal base load. The boilers can both be set on a minimal base load during low load operation hours. The measure can save 72 MWh/year = -1.5% of the stadium total heat/fuel use
- *Individual room control* - the measure consists of controlling the temperature room by room. In this way rooms which are not used are not heated or controlled. The measure can save 59 MWh/year = -1.2% of the stadium total heat/fuel use
- *Conversion to hot water dishwasher* - the measure consist of changing the heating of the hot water dishwasher from electrical to thermal heating. The measure increases heat/fuel use by 95 MWh/year = +1.4% of the stadium total heat/fuel use, but saves 102 MWh/year = -1.4% of the stadium total electricity use.
- *Disconnect other functions from the heating circuit* - All the rooms in a stadium are integrated in the ventilation system. The measure consists of disconnecting rooms, restaurants or museums from the ventilation system, because they are heated/cooled but not used. The measure can save 48 MWh/year = -1.0% of the stadium total heat/fuel use and 25 MWh/year = - 0.3% of the stadium total electricity use
- *Free cooling* - When the outside temperature is below 15 degrees the outside air can be used as free cooling for data and electricity rooms. The measure can save 116 MWh/year = -1.6% of the stadium total electricity use.
- *Turn of cold consumers* - Most of the time cold consumers are left on while they are not used. The measure consists of turning of cold consumers which are not used like refrigerators, air-conditioners etc. The measure can save 51 MWh/year = -0.7% of the stadium total electricity use.
- *Temperature adjustment MSR, ELT and mobile rooms* - These electricity and air control rooms can operate when it is 20 degrees. However, they sometimes operate

when it is 23 degrees. Each degrees can save 10% energy. The measure can save 109 MWh/year = -1.5% of the stadium total electricity use.

- *Adjust operating hours of cooling units in offices* - the measure consists of increasing the savings of the cooling units in offices. The workload of the cooling units is better adjusted to the working hours in the offices. The measure can save 33 MWh/year = -0.4% of the stadium total electricity use.
- *Retrofitting a differential pressure regulator for cold* - the measure consist of exchanging a two-way valve with a one way control valve and retrofit the differential pressure regulator. The measure can save 233 MWh/year = -3.1% of the stadium total electricity use.
- *Switch of the kiosks* - in the kiosks not all consumers are switched off. The measure consists of switching off the consumers during the non event time and control the switching off. The measure can save 43 MWh/year = -0.6% of the stadium total electricity use.
- *1/3 circuit lighting* - When there is no event many rooms, corridors and areas are not used. The measure consists of a system which only uses 1 out of every 3 lights. The measure can save 34 MWh/year = -0.5% of the stadium total electricity use.
- *Switch off the hot water boiler in the toilets* - hot water is continuously heated in the boiler at the toilet. Also when there is no event. The boiler must be switched of when there is no event or use. The measure can save 28 MWh/year = -0.4% of the stadium total electricity use.
- *Partly lighting in business club* - sometimes conference rooms of business halls are used, however only a part of the room or hall is used. The measure consists of a system which can partly use the lighting in a room or hall. The measure can save 22 MWh/year = -0.3% of the stadium total electricity use.
- *Lighting*, a stadium can retrofit the lighting department which ensures a electricity savings of 54%. The measure can save 891 MWh/year. (Dietrich et al., 2011).

The total amount of **saved energy with measure package 3 is 2,181 MWh/year**. The measures save both electricity and heat/fuel. The electricity demand decreases with 23.1% respectively 1,730 MWh. The heat/fuel demand decreases with 9.4% respectively 451 MWh. The total investment for **energy saving package 3 is 1,548,130€** (Merz, 2011).

4.2 Overview: measure packages + potential saving

In the Table 6,7 and 8 the energy saving measure packages are shown to give a clear overview of the measures and their potential energy savings.

Table 6. energy measure package 1

Energy saving measures	Potential saving (MWh/year)	
	Electricity	Heat/fuel
Combined heat supply with absorption chiller	0	107
Heat/fuel recovery in HVAC systems	0	227
Under floor heat control	0	142
Optimization of under soil field heat	0	71
Optimization of natural air exchange	0	334
Raum talk in boxes	317	0
Raum talk in arena/BMS/EIB Bus	2,833	0
Lighting upgrade	891	0
Total	**4,041**	**881**
Total	**4,922**	
Costs	1,896,050€	

Table 7. energy measure package 2

Energy saving measures	Potential saving (MWh/year)	
	Electricity	Heat/fuel
Measures in the boxes	0	95
Hydraulic commissioning heat system	0	191
Reduce the air flow rate	0	204
Measures soil heat	0	381
Measures in the basement garage	144.5	0
Switch off consumers in the kiosk	353	0
Upgrade the BMS	109	0
Reduce the base load	476	0
Miscellaneous Measures	82	0
Lighting upgrade	891	0
Total	**2,055.5**	**871**
Total	**2,926.5**	
Costs	1,593,600€	

Table 8. energy measure package 3

Energy saving measures	Potential saving (MWh/year)	
	Electricity	Heat/fuel
Air quality sensors	43	84
Exhaust gas heat/fuel exchanger	0	91
Integration of field heat in network	0	72
Night setback and adaptation of heat curve	0	91
Boiler control optimization	0	72
Individual room control	0	59
Conversion to hot water dishwasher	-102	+65
Disconnection from heat/fueling circuit	25	48
Free cooling	116	0
Turn of cold consumers	51	0
Temperature adjustment in rooms	109	0
Adjust operating hours of cooling units	33	0
Retrofitting a differential regulator for cold	233	0
Switch of the kiosks	43	0
1/3 circuit lighting	34	0
Switch off hot water boiler in de toilets	28	0
Partly lighting in business club	22	0
Lighting upgrade	891	0
Total	**1,730**	**451**
Total	**2,181**	
Costs	1,548,130€	

4.3 Distribution of measures

The electricity measures of the packages are now checked if they are focused on the most important types of electricity use selected in the previous chapter. The target functions are air handling units, lighting and kitchen appliances. The measures deal with these electricity consumers. The distribution is shown in Figure 4.

Air handling unit

- Raum talk in boxes
- Raum talk in arena/BMS/EIB Bus
- Upgrade the BMS
- Air quality sensors
- Disconnect other functions from heating circuit
- Free cooling
- Temperature adjustment control rooms
- Adjust operating hours of cooling untis in offices

Lighting

- Measures in the basement garage
- 1/3 lighting system
- Partly lighting system in business club
- Lighting upgrade

Kitchen appliances

- Switch off consumers in kiosk
- Conversion to hot water dishwasher
- Turn off cold consumers

Other

- Reduce the base load
- Miscellaneous Measures
- Retrofit differential pressure regulator for cold

Figure 4. Target functions electricity and measures. Footnote: measures 6 and 7 of package 1, measure 7 of package 2 and measures 1,8,9,11 and 12 of package 3 focus on the target area air handling unit. Measure 5 of package 2 and measures 15 and 17 of package 3 focus on lighting. Measure 6 of package 2 and measure 7,10 and 14 of package 3 focus on kitchen appliances. At last measures 8 and 9 of package 2 and measure 13 of package 3 focus on the target area other.

The heat/fuel measures of the packages are now checked if they are focused on the most important types of heat/fuel use selected in the previous chapter. The target functions are space heating, field heating and hot water. The measures deal with these heat/fuel consumers. The distribution is shown in Figure 5.

Space heating & hot water

- Combined heat supply with absorption chiller
- Heat recovery in HVAC systems
- Under floor heating control
- Measures in the boxes
- Hydraulic commissioning heating system
- Reduce the air flow rate
- Air quality sensors
- Nightsetback and adaptation of heat curve
- Individual room control
- Disconnect other function from heating circuit
- Switch of hotwater boiler in toilet

Field heating

- Optimization of under soil field heating
- Optimization of natural air exchange
- Measures soil heating
- Integration of fieldheating in network

Other

- Exhaust gas heat exchanger
- Boiler control optimization

Figure 5. Target functions heat/fuel and measures. Footnote: measures 1,2 and 3 of packages 1 and 2 and measures 1,4,6 of package 3 focus on the target areas space heating & hot water. Measures 4 (both package 1 and 2) and 5 of package 1 and measure 3 of package 3 focus on field heating. Measure 2 and 5 of package 3 focus on the target area other.

Almost all the measures of the selected packages focus on the identified target functions. These functions are of most interest and the functions are dealt with according to the “low-hanging fruit” principle. This is a straightforward principle, in which the easiest possibilities or goals are taken into account first i.e. the target functions with the highest percentage of energy consumption in a stadium, because of their high potential to save energy.

4.4 Change in energy consumption

The electricity and heat/fuel consumption both decrease when one of the packages is implemented in the stadiums. The changes in electricity and heat/fuel consumption of the Green Arena is compared with the stadium of the specific package. In Table 9, 10 and 11, on the next page, the change in electricity and heat/fuel consumption is shown for each package.

Table 9. Package 1: Imtech Arena, results (MWh)

Stadium	Before	After	Before	After	Before	After
	Total energy use	Total energy use	Energy use electricity	Energy use electricity	Energy use heat/fuel	Energy use heat/fuel
Green Arena	12,268	7,346	0.140/m^2	0.065/m^2	0.090/m^2	0.073/m^2
Imtech Arena	11,450	7,329	0.094/m^2	0.039/m^2	0.135/m^2	0.110/m^2

In the Green Arena and Imtech Arena the electricity consumption both are reduced by half. The heat/fuel consumption of the Green Arena decrease a bit, but the heat/fuel consumption of the Imtech Arena decreases more because the total heat/fuel consumption is much larger which ensure a bigger impact.

Table 10. Package 2: Commerzbank Arena, results (MWh)

Stadium	Before	After	Before	After	Before	After
	Total energy use	Total energy use	Energy use electricity	Energy use electricity	Energy use heat/fuel	Energy use heat/fuel
Green Arena	12,268	9,341.5	0.140/m^2	0.116/m^2	0.090/m^2	0.073/m^2
Commerzbank	10,515	7,749	0.138/m^2	0.114/m^2	0.126/m^2	0.103/m^2

In the Green Arena and Commerzbank Arena the electricity consumption both decrease with almost the same amount. Also with this package the heat/fuel consumption of the Green Arena decrease a bit, but the heat/fuel consumption of the Commerzbank Arena decreases more because the total heat/fuel consumption is larger which ensures a bigger impact.

Table 11. Package 3: Allianz Arena, results (MWh)

Stadium	Before	After	Before	After	Before	After
	Total energy use	Total energy use	Energy use electricity	Energy use electricity	Energy use heat/fuel	Energy use heat/fuel
Green Arena	12,268	10,087	0.140/m^2	0.108/m^2	0.090/m^2	0.081/m^2
Allianz Arena	21,741	19,044	0.179/m^2	0.154/m^2	0.114//m^2	0.103/m^2

In the Green Arena and Commerzbank Arena the electricity and heat/fuel consumption both decrease with almost the same amount. This is because the electricity and heat/fuel consumption is twice as high in the Allianz Arena than in the Green Arena.

Overall, in the result tables of the measure packages several interesting things can been seen. First, the total energy savings of package 1 are almost twice as much as the energy savings of package 2 and 3 times the savings of package 3. The difference can also be seen in the costs of the packages, where package 1 is the most expensive one and package 3 the less expensive one. Secondly, in package 1 a larger focus on electricity can be seen. Whereas in package 2 and 3 the focus is a little bit more on electricity than heat/fuel. Thirdly, package 1 and 2 both ensure large energy savings as a result of which the stadiums have a total energy use less than 10,000 MWh/year. Fourthly, the heat/fuel use per m^2 of the Green Arena is quite low in comparison with the other three stadiums. This is due to the low average heat/fuel use of stadiums and the large footprint.

4.5 Conclusion

In stadiums many small and large things can be fixed, replaced or optimized to decrease the energy use, but only the changes which have substantial influence on the energy use of the target functions are important. Hence, the list of energy saving measures in packages consists of measures which significantly decrease the energy use in target areas of a stadium.

Package 1 can save 54% of the electricity demand and 18.4% of the heat/fuel demand. Interesting measures from this package are the RAUM-talk system for electricity (-3,150MWh/year) and optimization of natural air exchange for heat/fuel (-334MWh/year). Package 2 can save 27.5% of the electricity demand and 18.2% of the heat/fuel demand. Interesting measures from this package are switching off of the consumers in the kiosk for electricity (353MWh/year) and measures for the soil heating for heat/fuel (381MWh/year). Package 3 can save 23.1% of the electricity demand and 9.4% of the heat/fuel demand. Interesting measures from this package are free cooling (-116MWh/year) and temperature adjustment in the rooms (109Mwh/year) for electricity and air quality sensors for heat/fuel (84MWh/year) . The measures RAUM talk and upgrade lighting are the ones that save the most electricity, respectively 3,315 MWh/year and 891 MWh/year.

The potential to save electricity is much higher than to save heat/fuel when looking at these packages. A reason for that is that the electricity consumption of the stadium is higher than the heat/fuel consumption. In comparison with the findings in the research of Dietrich et al. (2011) stadiums in the US can also save almost twice as much electricity than heat/fuel.

Nevertheless, these packages are not the maximum technical potential so other and more measures can also be implemented to further decrease the energy consumption of a stadium. However, the measures need to address both the electricity demand and heat/fuel demand. This ensures a total approach, and not only from one side, of minimizing the energy consumption. In this way a stadium can be transformed into a green stadium.

The working method of the Trias Energatica is used now. First, the energy demand is reduced by the implementation of energy saving measures i.e. energy savings. Secondly, the remaining part of the energy use of the stadium (and the additional part) is covered by the use of renewable energy technologies e.g. energy supply. The selection and analysis of the renewable energy technologies is done in the next chapter.

5. Renewable Energy Technologies

The available renewable energy technologies within stadiums are reviewed and analyzed to create a list of most important and frequently used technologies in stadiums to transform it into an energy producing system. In paragraph 5.1 each of the technologies is dealt with separately to go further into detail. A description of the technology is given and the most important figures are shown as well as the energy supply potential per year. In paragraph 5.2 an overview of the available renewable energy technologies and their potentials per year is shown to give a clear overview. At last in paragraph 5.3 the conclusion of the chapter is given.

5.1 Technologies

The renewable energy technologies which are selected are commercially available on the market until 2020 and are applicable for stadiums (Ecofys, 2009)(EC, 2007). The selection, as with the measures, is also done according to the “low hanging fruit” principle. The technologies are well developed and used for many years on the market (IEA, 2010). For each of the technologies several figures are researched or calculated: the potential energy supply per year, costs, lifetime and the subsidy. In this way the technical potential of the renewable energy technologies in the Green Arena is calculated. The selected technologies are divided per type of renewable energy.

5.1.1 Wind energy

In the wind energy sector two main technologies are available: the wind turbine and the urban wind turbine. These technologies are selected, because they are well developed, commercially available and easy applicable. Hence these technologies have a high potential for renewable energy supply (Ecofys, 2009)(EC, 2007).

A wind turbine uses the natural wind to power a generator which generates electricity. Mainly, when the 3 blades are moving faster (with higher wind speeds) the turbine rotor will switch in a higher gear. The generator will convert the mechanical energy into electricity. A windmill or a whole windmill farm can be on land but also offshore. If the wind speed is between 4m/s and 15m/s the windmill generates electricity, but when the wind speeds get higher (>20-25m/s) the windmill will automatically shut down. The current wind turbines are between 80-100m high with rotor blades of 40-50m and have a power of 3MW (BWEA, 2011a) (Agentschap.nl, 2011).

The selected power of the wind turbines is 3MW, because this is the standard of the present supply. The costs of these wind turbines are around 1,400,000 €/MW, the operation & maintenance costs are 11 €/MW. The wind turbine has approximately 2,200 load hours (Agentschap.nl, 2011). In the research the choice is made for 1 wind turbine, because a comparable stadium in the Netherlands will install a wind turbine to supply the required electricity to make the stadium CO^2 neutral and to become an electricity producer. However, the high investment costs are also of big influence. (Duurzaamheidsprogramma, 2012) (Agentschap.nl, 2011). The figures are shown in Table 12.

Table 12. Data wind turbines

Data - wind turbines	
Energy supply (power 3MW)	6,750 MWh/year
Costs (initial investment)	4,200,000 €
Costs (O&M)	74,250 €
Lifetime	20 year
Subsidy	0.106€/kWh (15 years)

An urban wind turbine also uses the natural wind to power a generator which generates electricity. The generator will convert the mechanical energy into electricity. It is the same principle as a large wind turbine only on a smaller scale. The height of an urban wind turbine is around 10m and it has a power of 0.5-50kW. These urban windmills are mostly used in town (BWEA, 2011b) (MEZLI, 2011).

The selected power of urban wind turbines is 25kW. These are about the most powerful turbines available. The investment costs of such an urban wind turbine is around 30,000€. The turbine is operation & maintenance free and has approximately 880 load hours (MEZLI, 2011) (Agentschap.nl, 2011). In the Netherlands the stadium Euroborg installed 16 turbines on a roof of 18,350m^2, this is 1 urban wind turbine for each 1,150 m^2. If this is scaled to the Green Arena it will be 28 turbines on the roof of 33,120 m^2 (Raat, 2012). The figures are shown in Table 13.

Table 13. Data urban wind turbines

Data - urban wind turbines	
Energy supply (power 25kW)	22 MWh x 28 = 616 MWh/year
Costs (initial investment)	840,000€
Costs (O&M)	0
Lifetime	20 year
Subsidy	0.106€/kWh (15 years)

5.1.2 Solar energy

In the solar energy sector 3 main technologies are available: solar PV, solar collector and Concentrated Solar Power (CSP). The technologies solar PV and solar collector are selected, because they are well developed, commercially available and easy applicable. Hence these technologies have a high potential for renewable energy supply (Ecofys, 2009)(EC, 2009). The technology CSP is also well developed and commercially available, but not easy applicable certainly not at a stadium, therefore this technology is excluded (EC, 2009).

Solar cells are solar panels which use and convert solar radiation into electricity or heat. There are 2 commercial types available: silicon and thin-film cells. Due to research and development the costs of PV panels are reduced during the last 25 years. Solar panels are used residential (on the rooftop) and on commercial utility level (industrial power supply) (Andrews et al., 2007c) (Jacobson et al, 2010).

The selected power of the solar PV panel installation, in Wp which is the power output if the solar irradiation is 1,000 W/m^2, is 650,000Wp. An average percentage of covering the roof surface of the Green Arena with solar PV panels is taken from five stadiums. Respectively, Euroborg, Wankdorf stadium, Easy Credit stadium, stadium Mainz and Carerra football stadium. An average of 20% of the roof surface is covered with solar PV panels, reaching 6,500m^2. The costs of the installation are around 1.75€/Wp, the solar PV installation is operation & maintenance free and in the Netherlands the maximum annual electricity supply is multiplied by 0.88 thanks to the weather conditions (zonnepanelen-info, 2010a) (Siderea, 2011) (milieucentraal, 2012a). The figures are shown in Table 14.

Table 14. Data Solar PV electricity

Data - solar PV	
Energy supply (power 650.000Wp)	572 MWh/year
Costs (initial investment)	1,137,500€
Costs (O&M)	0
Lifetime	25 year
Subsidy ≥ 15kWp	0,11 €/kWh (15 years)

The solar collector is used to generate heat instead of electricity. The size of the solar collector system is set at 15% of the roof surface i.e. 4,875m^2. This is enough to cover almost 50% of the total heat/fuel demand of the Green Arena (= 4,782MWh/year) (Praktischduurzaam, 2012). The heated water can be used for hot water and also for the field heating system, because the water needs to be 50°C (Horstmann, 2010). The solar collector system is half as big as the PV system, because a surplus of electricity can be sent back to the grid and with heat this will not be possible. A small 5m^2 solar collector system can save around 270m^3 of gas a year which is respectively around 8.5 GJ of energy or 2.3 MWh a year in comparison with a boiler mainly used in stadiums. The solar collector system is as the solar PV installation O&M free (Milieucentraal, 2012b) (Praktischduurzaam, 2012). The figures are shown in Table 15.

Table 15. Data Solar collector heat

Data - solar collector	
Energy saving (4875m^2)	2,250 MWh
Costs (initial investment)	3,400,000€
Costs (O&M)	0
Lifetime	25 year
Subsidy ≥ 100m^2	27.77 €/GJ = 0.10 €/kWh (15 years)

5.1.3 Biomass

The definition of biomass is: "*Materials for which of the mass of the combustible components completely or substantially completely consists of carbon compounds from a short-CO2-cycle, noting that all optionally in the carbon compounds present material from a long CO2 cycle inevitable in the material must be present. It should not be any burning of plastics or admixture of plastics.* " (Coenen et al., 2008).

A biomass CHP plant is an energy plant where fuel (biomass) is converted into energy (electricity and heat). The name CHP stands for Combined Heat and Power. The biomass CHP plant is selected because it is a technology which can be used to address the heat and electricity consumption. Almost all technologies above are focused on only electricity. Also a bio CHP plant saves energy through generation of heat and electricity (as a 'by-product'). In this way the efficiency is higher than two separate plants for heat and electricity.

The biomass CHP plants, technical proven and commercially available, exist in different kinds of conversion systems such as fermentation, combustion, gasification and biodiesel (Coenen et al., 2008) (EC, 2009). All of the plants have different kinds of efficiencies, costs and subsidies. The fermentation and gasification bio CHP plants are not taken into account, because of the high costs, low efficiencies and the required nearness of the input of the biomass compared to the other two technologies (Coenen et al., 2008). The most important figures of the other two biomass plants are listed below in Tables 16 and 17. The size of these biomass CHP plants is not a problem, because at the Allianz Arena in München an 0.5 MWe CHP plant is installed which has dimensions of 10 by 15 meter (M. Wienchol, 2012). The indirect land use of the biomass is not taken into account, because a stadium can buy bio-diesel which is already manufactured.

The biomass CHP plants which are chosen supply 50% of the heat demand (= 2,400 MWh thermal). The other 50% of the heat is already provided by the solar collector system. The electrical and thermal operation hours of the CHP are both 5,500 hours/year. The operation & maintenance costs are 3% of the initial investment for each of the plants. The plants all have an expected lifetime of 30 years and obtain subsidies (Coenen et al., 2008).

The biomass combustion CHP plant makes use of the conversion of 'dry' biomass (e.g. wood) in flue gases. From the heat of the flue gas steam can be produced. This can produce electricity via a steam turbine. The biomass combustion CHP plant has an electric efficiency of 19% and a heat efficiency of 65%. The costs of the biomass plant are 7,500/ kWe (Coenen et al., 2008). The figures are shown in Table 16.

Table 16. Data biomass-combustion

Data - combustion		
Energy supply (0.130MWe)	Electricity 715MWh	Heat 2,446MWh
Costs (initial investment)	975,000€	
Costs (O&M)	29,250€	
Lifetime	30 year	
Subsidy	28.82 €/GJ (12year) = 0.10 €/MWh	

The biomass biodiesel CHP plant makes use of the direct use bio-diesel in a diesel engine. The biomass biodiesel CHP plant has an electric efficiency of 40% and a heat efficiency of 50%. The costs of the biomass plant are 1.700/ kWe. The figures are shown in Table 17.

Table 17. Data biomass-diesel

Data - diesel		
Energy supply (0.350MWe)	Electricity 1,925MWh	Heat 2,406MWh
Costs (initial investment)	595,000€	
Costs (O&M)	17.850€	
Lifetime	30 year	
Subsidy	28.7 €/GJ (12year) = 0.10 €/MWh	

There are two technologies described above to show different possibilities in order to cover 50% of the heat demand of the Green Arena. However, these two options cannot be implemented both so only one is taken into account in the further research: bio-diesel CHP.

5.2 Overview: technologies + potential saving

In Table 18 all the renewable energy technologies are shown to give a clear overview of the technologies and their potential energy savings on the basis of the Green Arena.

Table 18. Technologies and potentials

Renewable energy technology	Potential (MWh/year)	Costs (initial investment)	Costs (O&M)
Wind turbines - 3MW	E:6,750	4,200,000€	74,250€
Urban wind turbines - 25kwx10	E:616	840,000€	0
Solar PV - electricity - 6500m^2	E:572	1,137,500€	0
Solar collector - heat - 4875m^2	H: 2,250	3,400,000€	0
Biomass - combustion	E:715 H:2,446	1.631,250€	49,000€
Biomass - diesel	E:1925 H:2,406	917,000€	27,510€

The wind turbine is able to supply a huge amount of electricity in comparison with the other technologies. It is the most expensive technology with the highest O&M costs. The urban wind turbines and solar PV both can supply almost the same amount of electricity. The costs of the solar PV are 1/3 higher in comparison with the costs of the urban wind turbines. This is due to the different installation systems and the efficiency of the technologies. The solar collector system can supply 50% of the heat which is a large share, however the costs of the system are very high. The bio-diesel CHP plant is cheaper than the bio-combustion CHP plant and produces twice as much electricity. The choice to continue with this technology is very logical.

5.3 Conclusion

There are many possibilities in stadiums for renewable energy technologies. The technologies can be implemented in different sizes and numbers. This is dependent on the goals of the project and the costs. All the potentials calculated in this chapter are maximum energy potentials for the Green Arena.

The energy supply potential of the technologies is very large. For wind energy it is more than 7,000 MWh/year electricity, for solar energy it is 570 MWh/year electricity and 2,250 MWh/year heat/fuel and for biomass it is 1,925 MWh/year electricity and 2,406 MWh/year heat/fuel.

The technologies supply both electricity and heat. An important footnote is: the heat supply must not exceed the heat demand, because this heat cannot be used or sent back to the grid. However, the electricity supply may exceed the electricity demand, because the electricity can be sent back to the grid. This can be an additional income source for a stadium.

At first sight it can be seen that there will be a surplus of almost 2,500 MWh electricity per year if all the technologies are installed. The heat supply of the technologies is 4,656 MWh/year which is nearly 100% of the heat demand of the Green Arena.

The figures of the energy efficiency measure packages and renewable energy technologies are known by now. The next step is to see what the specific costs are for these measure packages and technologies. This is shown in the following chapter.

6. Marginal Cost-Supply Curve

In this chapter a marginal cost-supply curve is constructed in order to arrange the energy efficiency measure packages and renewable energy technologies by the specific costs of saved final energy or generated final energy in €/MWh. The cost-supply curve is shown on the next page.

In order to calculate the specific costs of saved final energy (C_{spec}) the next equation is used:

$$C_{spec} = \frac{\alpha \, . \, I + C - B}{\Delta E}$$

$$\alpha = \frac{r}{1 - (1 + r)^{-L}}$$

Where:
α. I = annual capital costs (α = the capital recovery factor, I = Initial investment)
C = Operation & Maintenance costs
B = annual benefits
ΔE = annual saved final energy
r = discount rate (6%, social perspective)
L = the lifetime of the measure/technology

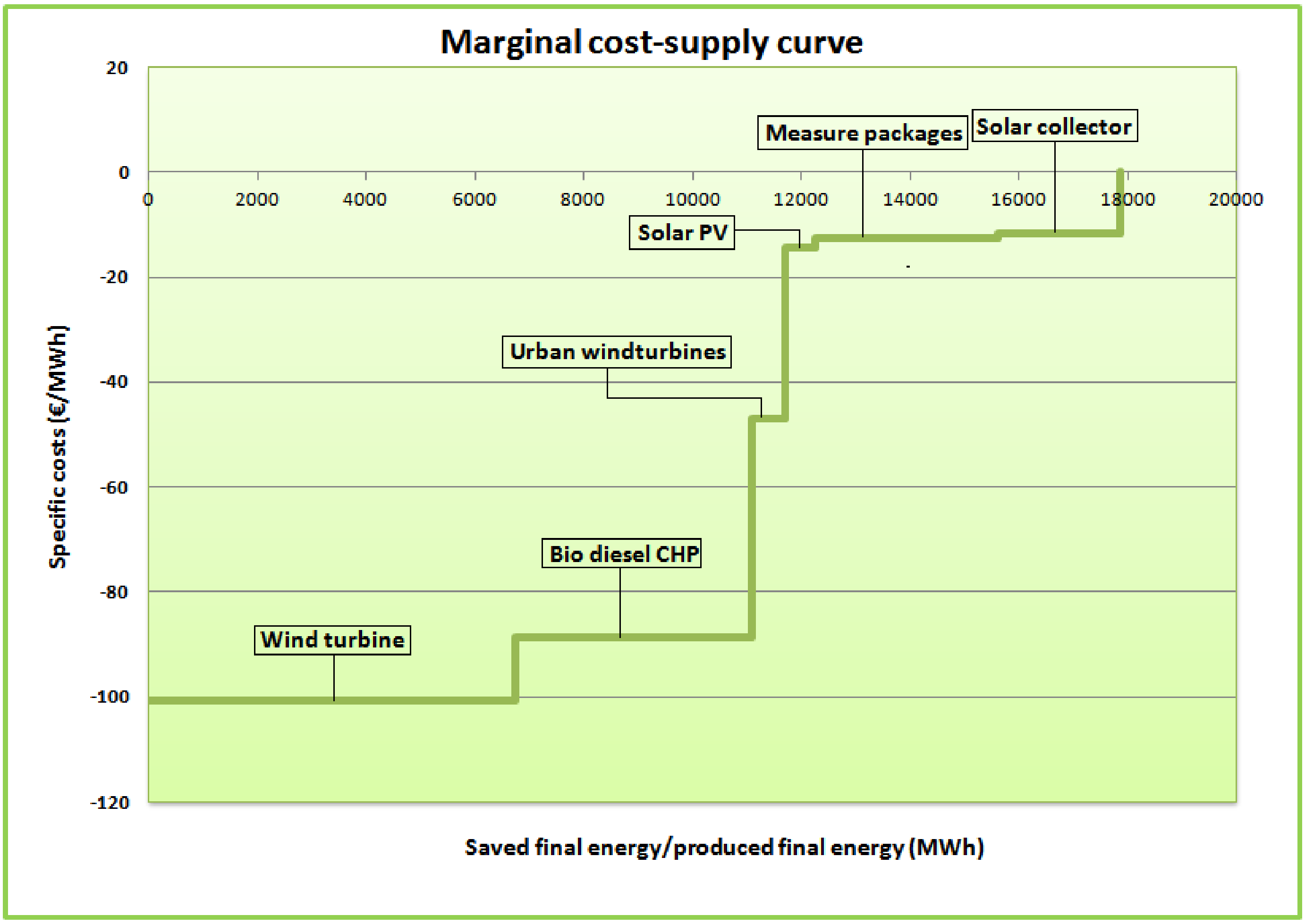
The capital recovery factor is an important part of the calculation of the specific costs. The capital recovery factor converts the present value into a ratio of annual payments over a specific lifetime (Schrestha, 2007). It is a function of the discount rate and the lifetime (of a technology or project). The discount rate used in the research is 6%, because this is a typical discount rate from a social perspective used for industrialized countries (Blok, 2007).

The specific costs are calculated using several units. Where I and O&M are costs, ΔE is the saved energy and B is the annual benefits. The annual benefits consist of subsidies for renewable energy (MEZLI,2012) and is an average between saved used electricity and returned electricity to the grid. The price for bulk use electricity is 0.06€/KWh or 60€/MWh which are actual prices from the market in 2012. The price for bulk use gas is 0.26€/m^3 or 30€/MWh which is also an actual price from the market in 2012 (Zicht op energie, 2012).

Also, in the Netherlands, subsidies are available for people or companies who produce renewable energy i.e. electricity and heat. All the different subsidies for each technology are shown in the previous chapter. The subsidies will help to make the payback time a lot shorter and the specific costs lower. First no energy has to be bought (saving money), secondly a subsidy can be received (earning money) and thirdly the surplus of (only) electricity can be sent back to the grid (earning money).

The measure packages save electricity and heat. So, a part of the annual benefits is from electricity savings and a part is from heat savings. The CHP plant produces electricity and heat. So, a part of the annual benefits is from electricity generation and a part is from heat generation. In comparison with the other technologies which produce only electricity or only produce heat.

In Graph 5 the measure packages and technologies which are available against certain specific costs contribute to the technical potential. In this scenario a hypothetical maximum potential of the amount of saved and produced energy (and investments) of a stadium can be calculated. However, due to the high costs, the economical potential is much more interesting. The measure packages and technologies below the zero-line are economically attractive from a social perspective. So these are the options which are the ones that can be implemented. Due to the overlap of the packages an average is taken from the specific costs.



Graph 5. Marginal cost-supply curve

The marginal cost-supply curve shows clearly the specific costs of all the average measure package and the renewable energy technologies. The two technologies which are economically the most attractive are a 3MW wind turbine and the bio diesel CHP plant. These two technologies have specific costs of -100€/MWh and -80€/MWh. The urban wind turbines are average performers with specific costs of -47€/MWh . The average measure package and solar collector system are just above the specific costs of -20€/MWh and therefore also very economically attractive. At last, the solar PV has the highest specific costs of more than -10€/MWh. Concluding, it can be said that all measure packages and renewable energy technologies are all economically attractive which is beneficial for the deployment of these sustainable options.

The information on the specific costs and the saved final energy or produced final energy is known by. From this point, on the basis of these figures, five case studies are conducted. These case studies are conducted to see what the technical and economical potentials of these stadiums are to become energy neutral or even energy producing. The potentials are dealt with within the next chapter.

Case Study: 5 stadiums in the EU


The Green Arena


Imtech Arena


The Euroborg


Commerzbank Arena


Allianz Arena

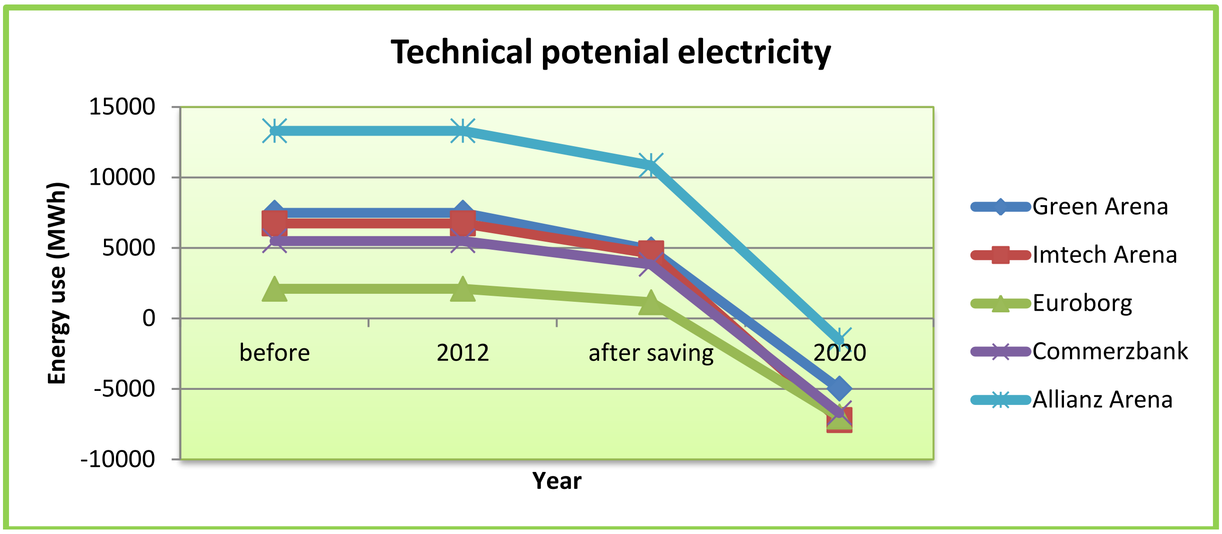
7. Technical potential

The technical potential of several stadiums is calculated, making use of the costs-supply curve made in the previous chapter. In paragraph 7.1 the technical potential of each of the stadiums is dealt with separately to show the specific electricity and heat potentials. The economical potential is excluded from the research, because all the options have negative specific costs. So the technical potentials in the research are also economically attractive, which means, in this research, the economic potential is the same as the technical potential.

Next to the technical potential also other elements are calculated (in paragraph 7.2); the total investment costs, the stadium revenues, the Net Present Value, the Payback Period and the number of households which can be provided with the electricity surplus. In paragraph 7.3, a conclusion is given.

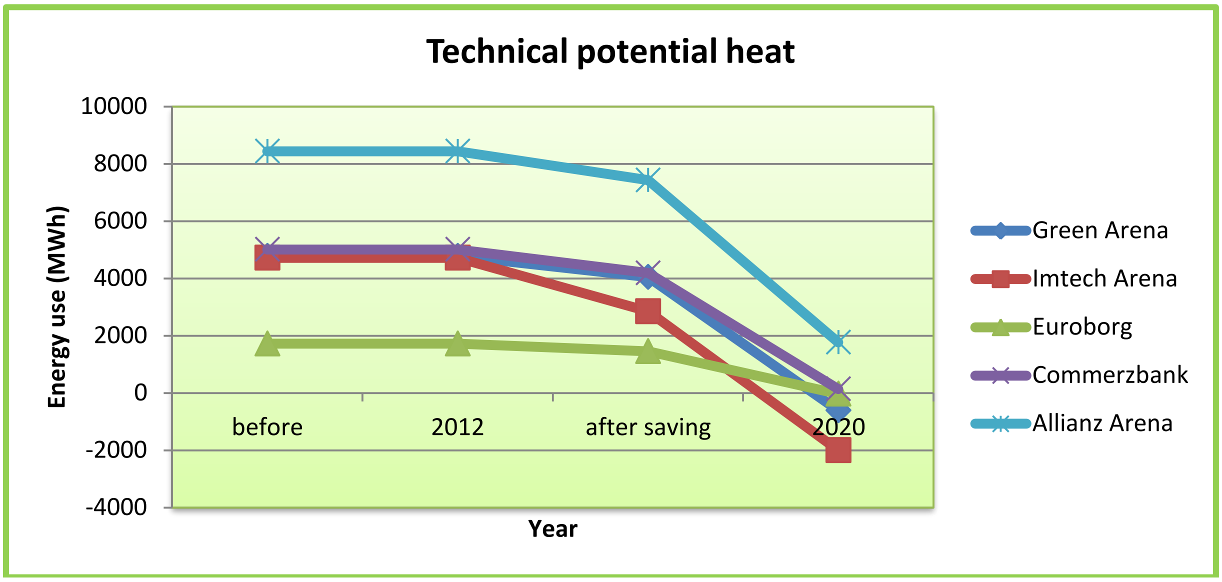
7.1 Technical potential

In Graph 6 and 7 the technical potential of each stadium is shown. First, the electricity and heat savings of the specific packages are shown for each stadium. So the Imtech Arena implements package 1, the Commerzbank implements package 2 and the Allianz Arena implements package 3. The Green Arena implements an average of these three packages and the Euroborg implements a scaled average of the three packages. Thereafter the electricity and heat production of all the technologies is shown. When the technical potential is clear the outcomes are analyzed and the most important figures are shown in the next paragraph.



Graph 6. Technical potential electricity

The technical potential for electricity production is very high. The electricity use of all stadiums decrease after implementing the specific measure package. The Allianz Arena has the largest decreases and the Euroborg the smallest. The other three stadiums are all average performers. However, after implementing the renewable energy technologies all stadiums produce a electricity surplus of over 5,000MWh/year, except for the Allianz Arena. This is due to the large electricity use (more than 13,000 MWh/year) of the Allianz Arena.



Graph 7. Technical potential heat

The technical potential for heat is less high than for electricity. This is due the fact that a surplus of heat cannot be sent back or used by other surrounding households. The heat use of the Allianz Arena and Imtech Arena decreases the most after implementing the specific package. The other three stadiums are all three average performers. However, after implementing the renewable energy technologies the Allianz Arena does not produce enough heat with the technologies. The Allianz Arena has still a shortage of around 1,700 MWh/year of heat which need to be complemented with regular boilers. The Green Arena, Euroborg and Commerzbank Arena all three are almost perfectly around the zero-line. The Imtech Arena has a huge surplus of heat, because the heat demand is already substantial lowered with the measure package. Implementing all renewable technologies is not required.

7.2 Electricity surplus, total costs, NPV and PBP

In this paragraph several important figures are calculated which are relevant for the project. Simply calculating the maximum amount of saved and produced energy is only one side of the project. The other side is the economic side which consists of the total investment costs, the stadium revenues, the NPV, the PBP and the number of households which can be provided with the electricity surplus. These figures will be shown in this paragraph.

7.2.1. Electricity surplus and households

If the specific measure package and all the renewable energy technologies are implemented there is a surplus of electricity. In graph 6 this is clearly shown. All the lines of the stadiums exceed the zero-line. The part below the zero-line is the surplus of electricity which van be returned to the grid for surrounding households. The amount of electricity surplus per stadium and the number of households which can be provided with this electricity are shown in Table 19.

Table 19. electricity surplus and households

Stadium	Electricity surplus (MWh)	Households
Green Arena	4985	1424
Imtech Arena	7216	2061
Euroborg	6967	1990
Commerzbank Arena	6701	1914
Allianz Arena	1518	433

7.2.2 Total investment costs vs. revenues

Related to all the measure packages and renewable energy technologies are costs. These costs are very substantial. Especially when implementing all the options. In order to see if the implementation of all the options is realistic and feasible for a stadium the total investment costs and revenues of the stadium are compared with each other. For the Green Arena an average revenue is taken from the other stadiums. This is shown in Table 20.

Table 20. total investment costs vs. revenues (Battle et al. 2012)(theoffside.com, 2009)(FC Groningen, 2010)

Stadium	Total costs	Revenues	Feasible
Green Arena	12,173,760€	133,275,000€	√
Imtech Arena	12,367,514€	128,800,000€	√
Euroborg	7,439,875€	17,100,000€	X
Commerzbank Arena	11,702,295€	65,800,000€	√
Allianz Arena	13,978,508€	321,400,000€	√

The total investment costs are for the larger stadiums all above 10 million Euros. Only the Euroborg has total investment costs of less than 8 million Euros. However, this investment is almost half of the total yearly revenues of the Euroborg which is 17 million Euros. Due to the relatively large part of the total revenues the investment costs can be a challenge. For the Commerzbank Arena the investment of 11 million Euros is more attractive. The total investment is 1/6 of the total revenues. The Green Arena, Imtech Arena and Allianz Arena all three have very high revenues. The total investment costs are 12 million for the Green

Arena, 12 million for the Imtech Arena and 14 million Euros for the Allianz Arena. Respectively, 1/10, 1/10 and 1/22 of the total revenues. Implementing the specific measure and all renewable energy technologies is feasible for these stadiums.

7.2.3 NPV and PBP

The NPV is calculated to see the current costs of the project. A project is considered to be attractive if the NPV is positive (Blok, 2007). The lifetime of the project is set on 25 years, which is the average lifetime of all technologies. Next the PBP is calculated to see how long it takes to pay off all the investment costs. The results are shown in Table 21.

Table 21. NPV and PBP

Stadium	Net Present Value	Payback Time (years)
Green Arena	7,575,240€	13.5
Imtech Arena	9,547,486€	12.5
Euroborg	4,906,625€	12.5
Commerzbank Arena	7,816,455€	13
Allianz Arena	12,034,492€	12

The NPV's of the stadiums are all positive. Hence, the project is economically very attractive. After the investment, the project will save 800,000€ or more each year. After the PBP this is pure profit. The PBP is more than 12 years for each stadium. The PBP can be a long period for the present management which probably will not be the management anymore in 12 years time. However, 12 years or more is not very long for a stadium which exists for many years.

7.3 Conclusion

As shown above the possibility to become an energy neutral stadium and produce electricity for surrounding households is present. The measure packages already save a reasonable amount of electricity and heat/fuel. When implementing the renewable energy technologies the heat/fuel use decreases, for all stadiums except the Allianz Arena, to zero which makes the stadiums self sufficient. The electricity use decreases much more, because a surplus can be sent back to the grid. 4 out of the 5 stadiums have an electricity surplus of more than 5,000 MWh/year. This surplus can be used to provide between 400-2,000 surrounding households.

However, the options are available against a certain price. The total investment costs (12 million Euros and more) are for the Green Arena, Commerzbank Arena, the Imtech Arena and Allianz Arena feasible, because these stadiums have very high revenues. The investment costs are respectively 1/10, 1/6, 1/10 and 1/22 of the revenues. The feasibility for the Euroborg is a challenge due to revenues which are not that high. The total investment costs are almost 1/2 of the revenues.

The NPV's of the projects are all positive so they are economically very attractive. On the other hand the PBP's of the projects are 12-13 years. This seems long, but for such a huge change the benefits will exceed the costs.

8. Energy Scenarios

In this chapter several energy scenarios are put together and calculated to show different outcomes of how to make a stadium energy neutral. The various potential alternatives have been analyzed to show a broader range of alternatives to make a stadium energy neutral which creates more complete solutions for all different kinds of stadiums. In paragraph 8.1 several energy scenario are proposed and the energy packages are set together and calculated. Thereafter, in paragraph 8.2, an overview of all the scenarios is shown. At last, in paragraph 8.3, a conclusion of the chapter is given.

8.1 Scenarios

In this chapter several energy scenarios are calculated and analyzed. The first scenario is chosen to show the possibility to become an energy neutral stadium with the lowest costs. The second and third scenarios are chosen to show the possibility to become an energy neutral stadium without using a certain technology. Scenario 2 excludes the wind turbine in the case of protest from the society against visual pollution. Scenario 3 excludes the bio-diesel CHP plant in the case of lack of space for the plant. The fourth and fifth scenarios are chosen to show the possibility to become an energy neutral stadium in the case of high energy prices.

The scenarios which are determined are shown in Table 22. These scenarios are determined, because of the variety of outcomes which can be used for other stadiums. Hence, the scenarios look at minimal costs, diverse used technologies and different kinds of energy.

Table 22. energy scenarios

Scenario	Name
1	The most economic energy neutral stadium
2	The energy neutral stadium without a wind turbine
3	The energy neutral stadium without a bio-diesel CHP plant
4	The stadium which is electricity neutral
5	The stadium which is heat/fuel neutral

Scenario 1: the most economic energy neutral stadium

In this scenario the possibility to realize the most economic energy neutral reference stadium is shown. In order to do this all measure packages and technologies need to be taken into account. This scenario is interesting for stadiums which have not that much money to spend.

Implementing a 3MW wind turbine, a 0.350MWe bio-diesel CHP plant and a solar collector system of 4,875 m^2 ensures an energy neutral stadium in the most economic way. There will be a surplus of electricity. This is not a problem, because this can be sent back to the grid and helps to shorten the PBP. The figures of the scenario are shown in Table 23and 24.

Table 23. energy change scenario 1

Green Arena		Scenario 1		After	
Electricity	Heat	Electricity	Heat	Electricity	Heat
7,486 MWh	4,782 MWh	8,675 MWh	4,656 MWh	-1,189 MWh	126 MWh

Table 24. Figures most economic neutral stadium

Total investment costs	Revenues	Surplus	Households	NPV	PBP
Euro, €	Euro, €	MWh		X 1000	Years
8,517,000	133,275,000	1,189	339	5,538	15

The total investment costs of scenario 1 are feasible for a stadium as the Green Arena with yearly revenues of more than 130 million Euros. The options produce a surplus of 1189 MWh electricity which can be sent to 339 households. The NPV of this scenario is positive and thus economically attractive. However, the PBP is quite long.

Scenario 2: energy neutral stadium without a wind turbine

In this scenario the possibility to realize an energy neutral stadium without a wind turbine is shown. In order to do this a large change in selected technologies must occur, because of the huge amount of electricity produced by the wind turbine. This scenario is interesting for stadiums or surrounding households of a stadium which do not want visual pollution.

Implementing measure package 1, 28 urban wind turbines, a solar PV system of 6500m^2, a 0.350MWe bio-diesel CHP plant and a solar collector system of 4875 m^2 ensures an energy neutral stadium without using a 3MW wind turbine. The fact is, if no wind turbine is installed all the other technologies need to be installed. The figures of this scenario are shown in Table 25 and 26.

Table 25. energy change scenario 2

Green Arena		Scenario 1		After	
Electricity	Heat	Electricity	Heat	Electricity	Heat
7,486 MWh	4,782 MWh	7,154 MWh	5,537 MWh	332 MWh	-755 MWh

Table 26. Figures stadium without wind turbine

Total investment costs	Revenues	Surplus	Households	NPV	PBP
Euro, €	Euro, €	MWh		X 1000	Years
8,190,000	133,275,000	0	0	4,081	16.5

As shown in Table 26, the total investment costs are less than in scenario 1. However, in this scenario no surplus of electricity is produced. This ensures a lower NPV and a longer PBP. A said above the total investment costs of scenario 2 are feasible with yearly revenues of more than 130 million Euros.

Scenario 3: energy neutral stadium without a bio-diesel CHP plant

In this scenario the possibility to realize an energy neutral stadium without a bio-diesel CHP is shown. In order to do this a change in selected technologies must occur, because the CHP produces both heat and electricity. Especially the heat production is an important factor which cannot be taken into account in this scenario. This scenario is interesting for stadiums which do not have the space for the bio-diesel plant.

Implementing a 3MW wind turbine, 28 urban wind turbines and huge solar collector system of 9,750 m2 (= 30% of the roof surface) ensures an energy neutral stadium without a bio-diesel CHP plant. The figures of the scenario are shown in Table 27and 28.

Table 27. energy change scenario 3.

Green Arena		Scenario 1		After	
Electricity	Heat	Electricity	Heat	Electricity	Heat
7,486 MWh	4,782 MWh	7,366 MWh	4,500 MWh	120 MWh	282 MWh

Table 28. figures stadium without bio-diesel CHP

Total investment costs	Revenues	Surplus	Households	NPV	PBP
Euro, €	Euro, €	MWh		X 1000	Years
11,840,000	133,275,000	0	0	1,119	23

The total investment costs for this scenario are more than 11 million Euros, which is very expensive. It is almost 1/10 of the total revenues of the Green Arena. No surplus is produced so this will not help to reduce the PBP. The NPV of this scenario is positive so it is economically attractive. Still, the PBP is 25 years. This is due to the high investment costs of the solar collector system (= 6.8 million Euros).

Scenario 4: electricity neutral stadium

In this scenario the possibility to realize an electricity neutral stadium is shown. In order to do this only the electricity side is taken into account without looking at the heat/fuel demand. This scenario is interesting for stadiums which have large electricity bills due to high usage or high electricity prices.

Implementing a 3MW wind turbine, a solar PV system of 6,500 m^2 and 8 urban wind turbines are able to ensure an electricity neutral stadium. The figures of this scenario are shown in Table 29 and 30.

Table 29. energy change scenario 4

Green Arena		Scenario 1		After	
Electricity	Heat	Electricity	Heat	Electricity	Heat
7,486 MWh	4,782 MWh	7,498 MWh	0	-12 MWh	4,782 MWh

Table 30. figures electricity neutral stadium

Total investment costs	Revenues	Surplus	Households	NPV	PBP
Euro, €	Euro, €	MWh		X 1000	Years
5,577,500	133,275,000	12	3	3,813	15

The total investment costs of realizing an electricity neutral stadium are 5.5 million Euros. In comparison with the total revenues it concerns a 1/20 part, so this scenario is feasible. The minimal surplus can be used to provide electricity for 3 surrounding households. The NPV is positive so economically attractive. The PBP is 15 years which is quite long. If a stadium only wants to tackle the electricity bill this is a good option.

Scenario 5: heat/fuel neutral stadium

In this scenario the possibility to realize a heat/fuel neutral stadium is shown. In order to do this only the heat/fuel side is taken into account without looking at the electricity demand. This scenario is interesting for stadiums which have large heat/fuel bills due to high usage or high heat/fuel prices.

Implementing a solar collector system of 4,875 m2 and a bio-diesel CHP ensure a heat/fuel neutral stadium. The figures of this scenario are shown in Table 31 and 32.

Table 31. energy change scenario 5

Green Arena		Scenario 1		After	
Electricity	Heat	Electricity	Heat	Electricity	Heat
7,486 MWh	4,782 MWh	1,925 MWh	4,656MWh	5,561 MWh	126 MWh

Table 32. figures heat/fuel neutral stadium

Total investment costs	Revenues	Surplus	Households	NPV	PBP
Euro, €	Euro, €	MWh		X 1000	Years
4,317,000	133,275,000	0	0	1,506	18.5

The total investment costs of scenario 5 are 4 million Euros. However, the PBP is 18.5 years, because the gas price is not that high in comparison with the electricity price. The NPV is positive so still with a long PBP this scenario is economically attractive.

8.2 Overview: scenarios

In Table 33 an overview of all the scenarios is given. The most important figures as energy produced, total investment costs, NPV and PBP, are shown.

Table 33. Overview scenarios

Scenario	Energy produced (MWh)		Total investment	NPV	PBP
	Electricity	Heat	Euro, €	X 1000	Years
1	8,675	4,656	8,571,000	5,538	15
2	7,154	5,537	8,190,000	4,081	16.5
3	7,366	4,500	11,840,000	1,119	23
4	7,498	0	5,577,500	3,813	15
5	1,925	4,656	4,317,000	1,506	18.5

Scenario 1 produces the most energy, has the highest NPV and the lowest PBP. In comparison with scenario 2 it has almost the same total investment costs. However, scenario has a lower NPV and a higher PBP. Scenario 3 is very expensive, because a relative cheap technology (bio-diesel CHP plant) is excluded. This ensures that the heat/fuel demand must be covered by a much more expensive technology (solar collector). Although the scenario has a positive NPV, the PBP is very long. Scenario 4 and 5 are the cheapest, which is due to looking only at one side of the energy demand (electricity of heat/fuel). These scenarios are feasible, nevertheless it is not a total approach of the energy issue.

8.3 Conclusion

There are many ways to realize an energy neutral stadium. In order to do this several technologies can be used dependent on the goal of the stadium, the economics and the financial strength. However, some technologies can also be excluded to reach the goal of an energy neutral stadium.

Realizing a total energy neutral stadium will require a minimal total investment of 8 million Euros. If the wind turbine is excluded other technologies can be used to cover the electricity demand. The total investment costs remain around the 8 million Euros. Nevertheless, the PBP of the project will increase because of the lack of electricity surplus. Next to that a stadium can also be energy neutral without using a bio-diesel CHP plant. This option ensures much higher investment costs (11 million Euro) and a PBP of more than 20 years.

When only looking for an electricity neutral or heat/fuel neutral stadium the total investment costs are around 5 million Euros. These scenarios only cover one side of the energy use. In certain situations, e.g. high electricity or heat/fuel prices, this is wanted. The electricity neutral scenario has a much lower PBP than the heat/fuel neutral scenario. Still the investment costs are lower for the electricity neutral scenario.

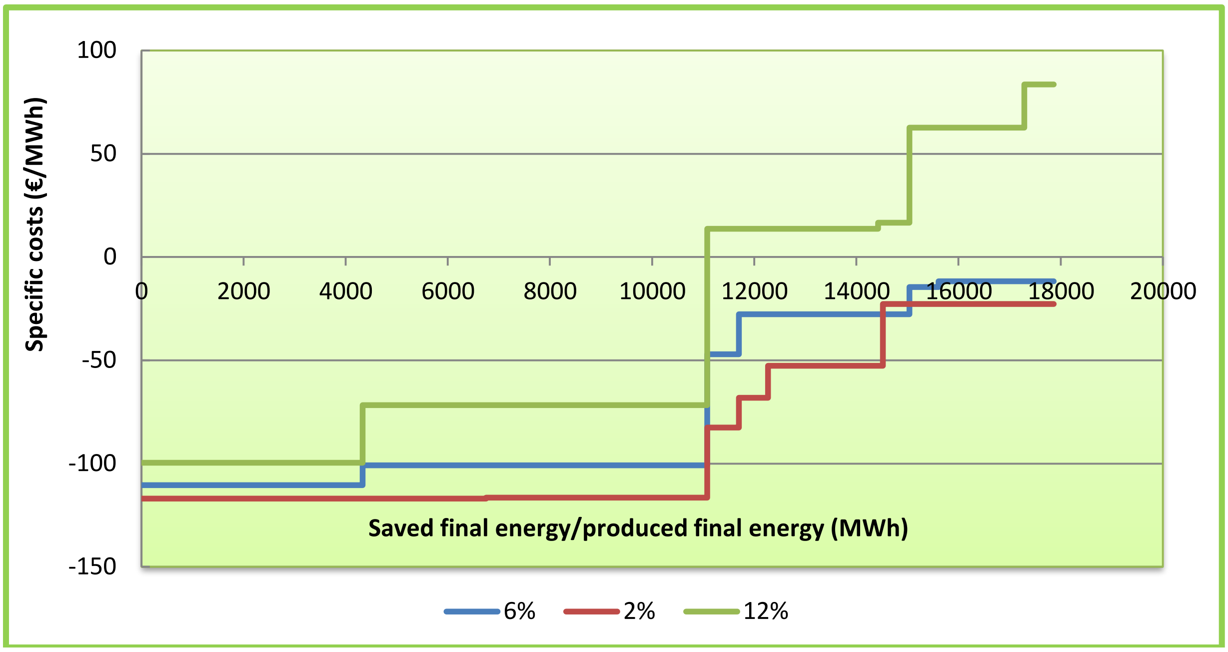
All the scenarios have positive NPV values, for a lifetime of 25 years, so it can be said that all the scenarios are economically attractive. From an economic and sustainable point of view it would be logical to address the total energy demand of a stadium. Therefore scenario 1 is the best option. This scenario has the highest NPV and the lowest PBP.

9. Discussion

Considering the analysis, there are some facts that can have an impact on the results. Therefore a sensitivity analysis is done on four important facts/assumptions.

Change in discount rate

One of these facts is the discount rate, the report uses the value of 6%. This number was chosen because Blok (2007) stated that the discount rate of 6% is a typical discount rate from a social perspective used for industrialized countries. In Graph 8 the difference in outcome, when this assumption is changed, can be seen.

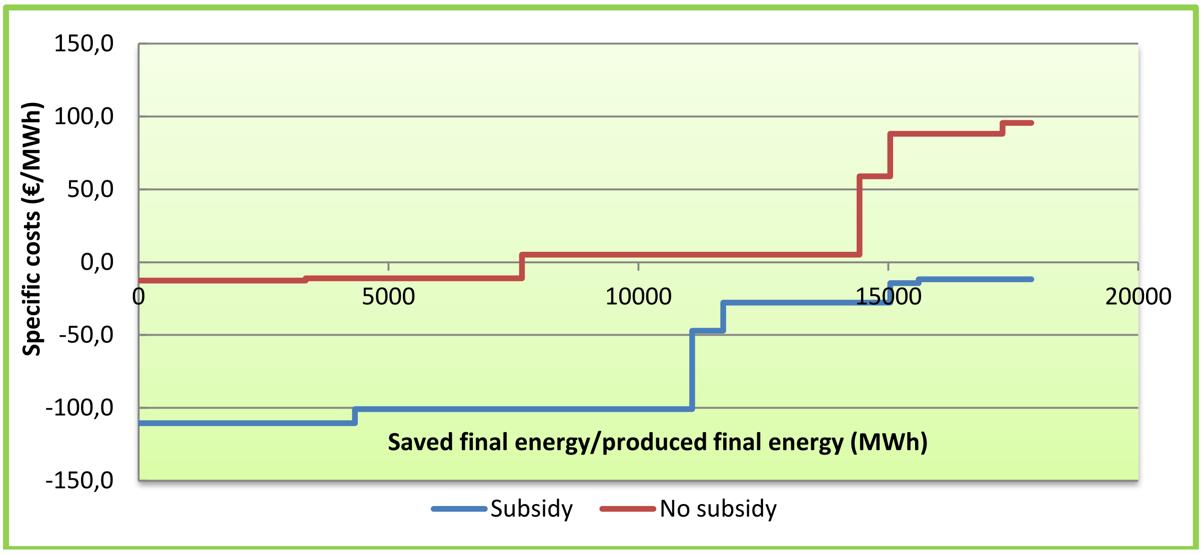


Graph 8. Sensitivity analysis, change in discount rate

As was expected, a lower discount rate (red) for the measure package and technologies has a positive outcome on the results. The specific costs are lowered by the lower discount rate. A higher discount rate (green) raises the specific costs of all the options. The general outline of the graph remains the same. However, a discount rate of 12% ensures that the largest part of the technologies have positive specific costs.

Change in subsidy

Another fact that has been used, that could vary, are the obtained subsidies for renewable energy. In the research the assumption is made that all the energy produced by renewable energy technologies receive subsidies for 12 or 15 years. Graph 9 shows the impact if there no subsidies are given.

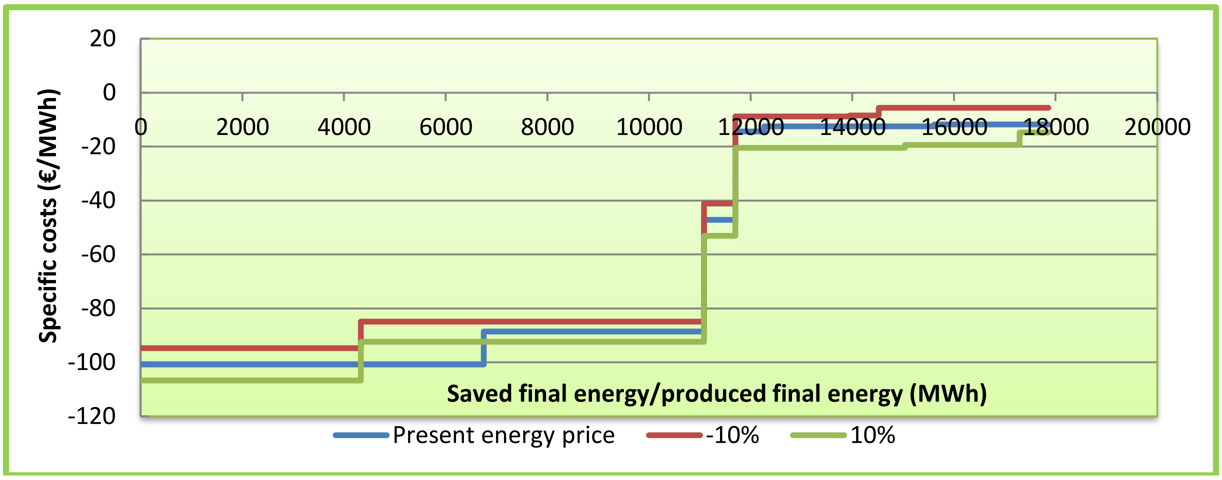


Graph 9. Sensitivity analysis, change in subsidy

The graph shows that if there are no subsidies given for production of renewable energy only the measure package and the bio diesel CHP plant will have negative specific costs. All other renewable energy technologies will have positive specific costs, indicating they are not very economically attractive. In other words, it is very good that renewable energy production is subsidised to stimulate sustainable development.

Change in electricity price

The next fact which is highly variable is energy price. In the research the electricity price is set at 60€/MWh and the gas price is set at 30€/MWh. However, these prices are under high influence of the market and often vary substantially (Zicht op energie, 2012). In Graph 10 a change of +10% and -10% of the energy price is shown, which is a representation of the historical fluctuations of the energy prices (Zicht op energie, 2012) (energie vergelijken, 2012).

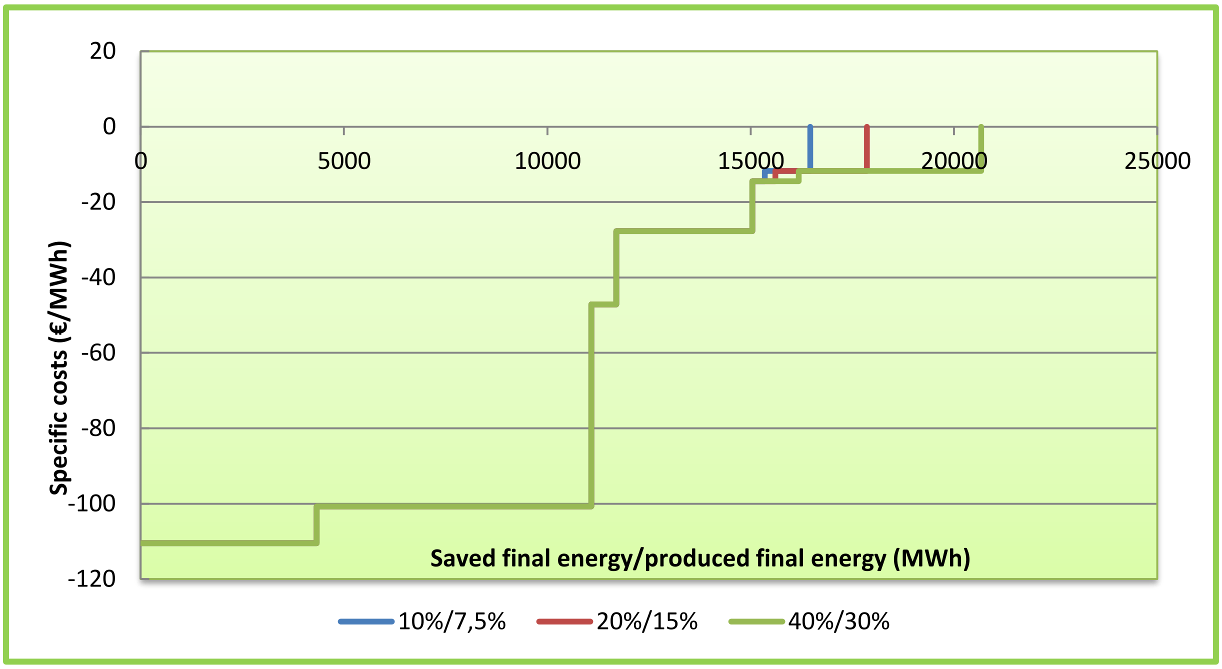


Graph 10. Sensitivity analysis, change in energy price

In the graph it can be seen that a change in energy price influence the specific costs. The +10% situation ensures lower specific costs, because the stadium does not need to buy this energy. Also the surplus of electricity can be sold for a higher price. In the -10% situation the specific costs increases. Not that much, because all the options still have negative specific costs. Due to the nuclear disaster in Japan, the closing of nuclear factories in Germany and unrest in the Middle-East there is a high pressure on the energy prices (Benergy, 2012). However, due to the financial crisis in Europe the energy prices are declining, because there is less use. Therefore both the changes are realistic.

Change in percentage roof covered

The last fact which is variable is the percentage of roof covered with solar PV and solar collector systems. The change in percentage is shown in Graph 11. Where the percentage is doubled and halved. This can be necessary when the roof cannot bear the weight or when no construction is applicable on the roof to fit the solar systems. In the research the roof is covered for 20% with solar PV panels and 15% with a solar collector system.



Graph 11. Sensitivity analysis, change in % roof covered

The graph shows clearly a change in technical potential when the percentage of roof covered changes. When the percentage doubles (green), the technical potential increase to more than 20,000 MWh/year. In the situation of halving the percentage of roof covered with solar PV and solar collector systems (blue) the technical potential decreases to 16,500MWh/year.

A change in discount rate to 2% is beneficial for the specific costs. In comparison with a change in discount rate to 12%, which will ensure higher specific costs. This is negative for the deployment of the renewable technologies. The change in energy prices does not have very much influence on the specific costs. The change from receiving subsidies to no subsidies has a large influence on the specific costs. When no subsidies are provided the specific costs of the renewable energy technologies increase that much that only two of the 6 options are still just economically attractive. The change will have large influence on the technical potential. Due to the higher costs it is less attractive. So, the deployment of renewable energy technologies is therefore dependent on subsidies to be economic. At last, the change in percentage roof covered will have substantial influence on the technical potential. It is logic, that a decrease percentage will decrease the technical potential and an increase in percentage will increase the technical potential.

The largest weak point of a marginal cost-supply curve analysis, is that the result is in fact a scenario, based on different assumptions. The effect of different assumptions has been shown in the sensitivity analysis, which in itself are just other scenarios. In this research it is tried to assume the most plausible values of different variables, but all those values are based on a continuing trend and does indeed not account for sudden changes (in the form of e.g. a financial crisis).

Moreover, each stadium is unique and therefore the size, use and implementation of energy saving measures and renewable energy technologies are specific for that stadium. Measures and technologies all need to be designed and adapted for a specific stadium. In this research all the measure packages from other stadiums were scaled to the reference stadium. This is a proper way to see the influence on the reference stadium. However, it is not 100% authentic.

Also, constructional data about other stadiums, plans to transform it into a green stadium and the energy usage of stadiums were not widely available. In addition a part of the data which was obtained at Imtech was classified and only for ‘in house’ use.

These facts can lead to uncertainty in the data used in the research.

10. Conclusion

The energy consumption of a stadium depends on the size, technologies used, number of events and the climate in which it's located. An average stadium in North-West Europe has a capacity of around 46,000 persons and covers more than 50,000 m^2 of land. The Green Arena, the reference stadium in this research, has an electricity use of around 7,500 MWh/year and the heat/fuel use of almost 5,000 MWh/year, resulting in a total energy use of over 12,000 MWh/year. 20% of this energy is used during events and 80% when no events occur. The functions which use the most electricity are the air handling unit and lighting. Concerning heat functions, these are space heating and field heating. These are the target functions which are of most interest for energy efficiency improvements.

In stadiums there are many energy saving measures available to substantially reduce the energy demand. Most of the time the measures are compiled in packages for a specific stadium. In this way the measures are adapted to the specific characteristics of the stadium. The measure packages used in this research contain multiple measures (8-18) which address both the electricity and heat/fuel demand. These measure packages can save up to 4,000 MWh/year electricity and 800 MWh/year heat/fuel.

Next to the energy saving measures there are many renewable energy technologies available to use in stadiums for energy production. The technologies selected in this research are wind turbines, urban wind turbines, solar PV, solar collectors and bio CHP plants. The energy supply potential of the technologies is very large. For wind energy it is more than 7,000 MWh/year electricity, for solar energy it is 570 MWh/year electricity and 2,250 MWh/year heat/fuel and for biomass it is 1,925 MWh/year electricity and 2,406 MWh/year heat/fuel.

A marginal cost-supply curve is constructed in order to arrange the energy saving measure packages and renewable energy technologies by the specific costs of saved final energy or generated final energy in €/MWh. All the measure packages and renewable energy technologies have specific costs between -110 €/MWh and -15€/MWh. This indicates that all the options are economically attractive (including subsidies), which is beneficial and crucial for the deployment of these sustainable options.

In order to see the impact of the energy saving measure packages and renewable energy technologies a case study is done regarding 5 European stadiums to check the technical potential in practice. The technical potential of the stadiums is to reduce the electricity demand to zero and produce a surplus of electricity of between 1,500-5,000 MWh/year, depending on their own electricity use. Next to that, the stadiums have the potential to reduce the heat/fuel demand to zero. The electricity surplus can be used to provide between 400-2,000 households of electricity. The surplus of electricity and zero heat/fuel demand shows that the stadium can be self-sufficient. The total investment costs of an energy saving project, dependent on the size of the stadium, are between 7-14 million Euros, which are high. However when comparing these costs with the yearly revenues of the stadiums, which are up to 300 million Euros, it should be feasible to implement them.

The Net Present Values of the projects are all positive (including subsidies), so the projects are economically very attractive. The Payback Periods of the projects are between 12-13 years. This seems long, but for such a huge change the benefits will exceed the costs.

Various potential alternatives are analyzed to show a broader range of alternatives to make a stadium energy neutral. This creates more complete solutions for all different kinds of stadiums. The scenario of realizing a complete energy neutral stadium will require a minimal total investment of 8 million Euros and has a PBP of 15 years. The scenario of excluding the bio-diesel CHP plant, in the case of limited space and still become energy neutral, will increase the investment costs to 11 million Euros and the PBP to 23 years. This due to other more expensive technologies that must cover the remaining energy which would be supplied by the bio-diesel CHP plant. When looking for an electricity neutral or heat/fuel neutral stadium, in the case of high energy prices, the total investment costs are around 5 million Euros and the PBP between 15-17 years. All these scenarios have positive NPV values (including subsidies) so it can be said that all the scenario are economically attractive.

The degree in which energy savings measures and renewable energy technologies can transform a stadium in an energy producing system is very high. The results of the research show positive NPV values (including subsidies) for the implementation of the energy saving measures and renewable energy technologies. This indicates that transforming a stadium in a renewable energy producing system is economically attractive. The main thing which will required is to do further research about specific stadiums to determine the specific needs and potentials. In this way maximum results can be achieved. It is time to take action and become a Green Stadium.

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