MSc Program
Renewable Energy in Central and Eastern Europe

Off-grid photovoltaic energy supply on the Kornati archipelago in Croatia - Substitution of a diesel generator by a photovoltaic system with battery backup

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Ao. Univ. Prof. Dr. Reinhard Haas

Marlene Buchinger, B.A. (FH)

0927419

Vienna, 30.09.2011

Affidavit

I, Marlene Buchinger, hereby declare

1. that I am the sole author of the present Master Thesis, "Off-grid photovoltaic energy supply on the Kornati archipelago in Croatia – Substitution of a diesel generator by a photovoltaic system with battery backup", 137 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, _______________ ____________________________

Date Signature

Abstract

The deployment of renewable energies in Croatia, and especially in the Kornati national park and along the coastal line in Dalmatia, is, apart from hydro power, underdeveloped. This work attempts to find a renewable and sustainable energy supply for these remote areas to substitute the existing diesel generators. This aims on the one hand for a cost-effective alternative for single households and on the other hand for a reduction in air pollution, i.e., emission of CO_2 and other toxic elements, of which locals, tourists and even the state will benefit.

Influenced by the prevailing conditions and the current legislative a small-scale PV plant with additional battery storage is considered and compared to a diesel generator in technical, economical and ecological respect. The research results of various existing studies are aggregated to evaluate the potential of such plants by comparing different scenarios. This comprises i.a. the future development of the PV and diesel prices. Based on the results for a single PV-plant, which outperforms a diesel generator with regard to emission and costs of more than 10,000 € over the lifetime of 20 years, the assumption is made that there is a potential for the implementation of about 5,000 small-scale PV plants in the respective area. Therewith, a substantial contribution towards a more sustainable energy production in Croatia is made.

Table of content

Abstract iii
Table of content iv
List of tables vi
List of figures viii
List of acronyms ix
1 Introduction 1
1.1 Motivation 1
1.2 Core objective of work 1
1.3 Citation of main literature 2
1.4 Method of approach 2
2 Technologies for renewable electricity production 4
2.1 Photovoltaic 4
2.2 Wind energy 12
2.3 Hydro power 14
2.4 Biomass 18
2.5 Geothermal 22
2.6 Excursus: Battery storage systems 23
2.7 Excursus: Diesel generators 25
3 Renewable energies in Croatia 26
3.1 Current use of RES 27
3.2 Legal requirements 28
3.3 Potential and future prospect of RES 30
4 Reference location Kornati archipelago 32
4.1 Croatian islands 32
4.2 Characteristics of the Kornati archipelago 33
4.3 Definition of the reference house 35
4.4 Sun radiation 38
4.5 PV plant configuration 40
4.6 Battery storage configuration 44
4.7 Diesel generator configuration 45

5 Economic evaluation 46
5.1 Price evaluation PV system 46
5.2 Price evaluation diesel generator system 52
5.3 Electricity costs 54
5.4 Net present value calculation 58
5.5 Sensitivity analysis 60
5.6 Comparison between PV and diesel generator 63
5.7 Comparison between PV and household electricity prices 67
6 Future scenarios and potentials 70
6.1 Development and scenarios of PV prices 70
6.2 Development and scenarios of diesel prices 73
6.3 Development and scenarios of electricity prices 75
6.4 Comparison between the assumed scenarios 79
6.5 Potentials 81
7 Conclusion 85
References xiv
Annex A Site visit Kornat xxvii
Annex B Consumption and specifications of electrical devices xxix
Annex C Sun radiation and further calculation data xxxi
Annex D PV plant and battery dimensioning xxxviii
Annex E Diesel generator dimensioning xliv
Annex F Financial analyses xlvii
Annex G Scenarios li

List of tables

Table 1: Commercial module efficiency 7
Table 2: Primary energy supply in Croatia in 2009 26
Table 3: Electricity generation from RES in Croatia in 2008 27
Table 4: Croatian RES feed-in tariffs in 2010 29
Table 5: Potentials and deployment rates for RES technologies in Croatia 30
Table 6: Electrical devices in the reference house 36
Table 7: Energy consumption in representative months 37
Table 8: Comparison of sun radiation part 1 38
Table 9: Comparison of sun radiation part 2 39
Table 10: Radiation at different inclination angles 41
Table 11: Heat coefficient 41
Table 12: Calculation of the daily energy yield in representative months 43
Table 13: Annual diesel operating hours 46
Table 14: Module prices in Croatia 47
Table 15: Comparison of Croatian module manufacturer’s prices 48
Table 16: Shares of system components costs 49
Table 17: PV system costs 50
Table 18: Price comparison of lead batteries 50
Table 19: Overall PV investment costs 51
Table 20: Annual PV O&M costs 52
Table 21: Overall diesel generator investment costs 52
Table 22: Annual diesel O&M costs 54
Table 23: Comparison of emission output diesel and PV 65
Table 24: Comparison of emission output gas and PV 69
Table 25: Emission output in the Kornati national park 83
Table 26: Emission output in the potential Croatian area 84
Table 27: Energy consumers within the reference house xxix
Table 28: Annual energy consumption of the reference location xxx
Table 29: Radiation data of Zadar/Zemunik xxxi
Table 30: Radiation data of Šibenik xxxii

Table 31: Srednja dnevna ozračenost prema jugu nagnute plohe [kWh/m²] xxxiii
Table 32: Mean daily sun radiation on a south orientated surface [kWh/m²] xxxiii
Table 33: Global horizontal irradiance (Wh/m²) xxxiv
Table 34: Radiation data for Vrulje at an inclination of 0° xxxiv
Table 35: Radiation data for Vrulje at an inclination of 15° xxxv
Table 36: Radiation data for Vrulje at an inclination of 30° xxxv
Table 37: Radiation data for Vrulje at an inclination of 45° xxxvi
Table 38: Radiation data for Vrulje at an inclination of 60° xxxvi
Table 39: Heat coefficients xxxvii
Table 40: Features of Solvis poly-crystalline modules xxxviii
Table 41: Solvis module performance under STC xxxix
Table 42: PV plant configuration xl
Table 43: Battery dimensioning xliii
Table 44: Specification diesel generator xlv
Table 45: Suggested diesel generator service intervals xlv
Table 46: Assumed diesel generator service intervals with time and cost estimations xlvi
Table 47: PV NPV calculation xlviii
Table 48: Diesel NPV calculation xlix
Table 49: PV sensitivity analysis l
Table 50: Diesel sensitivity analysis l
Table 51: Comparison of scenario calculations li

List of figures

Figure 1: Annual global irradiation on horizontal plane (MWh/m²) in Croatia........34
Figure 2: Solar home system with option of AC-generation.................................37
Figure 3: Comparison of mean daily sun radiation...39
Figure 4: PV LRMC distribution...56
Figure 5: Diesel LRMC distribution 57
Figure 6: Development of cumulative cash flows for PV and diesel 59
Figure 7: PV sensitivity analysis...61
Figure 8: Diesel sensitivity analysis 62
Figure 9: Diesel engine emissions under real combustion conditions 64
Figure 10: Development of PV LRMC 2008-2030..72
Figure 11: Development of diesel LRMC 2008-2030..75
Figure 12: Structure of household electricity prices 76
Figure 13: Development of the household electricity prices 2008-2030 79
Figure 14: Comparison of the price development 2008-2030.................................80
Figure 15: Location Zadar/Zemunik xxxi
Figure 16: Location Šibenik...xxxii
Figure 17: Description diesel generator xliv

List of acronyms

(in alphabetic order)

a	Annum, year
A	Rotor swept area
AC	Alternating current
Ah	Ampere hour
AM	Air mass
approx.	Approximately
a-Si	Amorphous silicon
BHA	British Hydropower Association
BWE	Bundesverband WindEnergie e.V
BOS	Balance of system
c	Cent
C	Centigrade
C_0	Net present value
Calc.	Calculatory
c_{BATT}	Battery investment costs
CCGT	Combined cycle gas turbines
CCS	Carbon capture and storage
CdS	Cadmium sulfide
CdTe	Cadmium telluride
CEE	Central and Eastern Europe
c_{FIX}	Fixed costs
c_{FUEL}	Fuel costs
CHP	Combined heat and power
CIGS	Copper indium gallium diselenide
c_{INV}	Investment costs
CIS	Copper indium diselenide
cm	Centimetre
C_n	Battery capacity

CO	Carbon monoxide
CO_2	Carbon dioxide
CPV	Concentrated PV
CRF	Capital recovery factor
c_{VAR}	Variable costs
d	Day
D	Diesel
DC	Direct current
DHMZ	Državni hidrometeorološki zavod, Meteorological and Hydrological Service
DGS	Deutsche Gesellschaft für Sonnenenergie e.V., German section of the International Solar Energy Society
DZS	Državni zavod za statistiku, Croatian Bureau of Statistics
E	East, longitude
EFG	Edge-defined film-fed growth
e.g.	Exempli gratia, for example
E_{IDEAL}	Ideal energy yield
EIHP	Energetski institut Hrvoje Požar, Energy institute Hrvoje Požar
EL, el	Electrical
EPIA	European Photovoltaic Industry Association
E_{REAL}	Real energy yield
ESHA	European Small Hydropower Association
et al.	Et alii, et aliae, and others
etc.	Et cetera
EU	European Union
EWI	Energiewirtschaftliches Institut an der Universität zu Köln, Institute for Energy Economics at the University of Cologne
F	Factor
F_s	Factor of autonomous days in the summer
F_w	Factor of autonomous days in the winter
FY	Final yield
g	Gram
GEMIS	Global emission model for integrated systems
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit, German Technical Cooperation

GWh	Gigawatt hour
h	hour
HC	Hydro carbon
HEP	Hrvatska Elektroprivreda, Croatian national electricity company
HERA	Hrvatska energetska regulatorna agencija, Croatian Energy Regulatory Agency
HIT	Heterojunction with intrinsic thin layer
H_2O	Water
HROTE	Hrvatski operator tržišta energije, Croatian Energy Market Operator
H_2SO_4	Sulfuric acid
Hz	Hertz
i	Interest
I	Investment
i.a.	Inter alia, among others
i.e.	Id est, this means
IEA	International Energy Agency
incl.	Including
incr.	Increasing
kg	Kilogram
km	Kilometre
km^2	Square kilometre
Kn	Kuna
kW	Kilowatt
kW_p	Kilowatt peak
kWh	Kilowatt hour
l	Litre
L	Loss
LRMC	Long run marginal costs
LT	Lifetime / depreciation time
m	Metre
m.	Million
m^2	Square metre
m^3	Cubic metre
max.	Maximum

µc-Si	Micro-cystalline silicon
min.	Minimum
mon.	Month
MSc	Master of Science
MW	Megawatt
MW_e	Megawatt electrical energy
MWh	Megawatt hour
MW_p	Megawatt peak
MW_t	Megawatt thermal energy
N	North, latitude
N_2	Nitrogen
NASA	National Aeronautics and Space Administration
n.d.	Not dated
nm	Nautical mile
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide
NPV	Net present value
O_2	Oxygen
ODS	Operator distribucijskog sustava, Distribution system operator
OECD	Organisation for Economic Co-operation and Development
OIE	Obnovljivi izvori energije, renewable energy sources
O&M	Operation and maintenance
ORC	Organic-Rankine-Cycle
p	Peak
P	Density of air
p.	Page
p.a.	Per annum, per year
P_n PV	Nominal power PV generator
PJ	Petajoule
pp.	Pages
PR	Performance ratio
prim	Primary
P_{th}	Theoretical wind power
PV	Photovoltaic

PVPS	Photovoltaic Power System Programme
PVX	PV Xchange
Q_{SOL}	Sun radiation
r	Radius
RES	Renewable energy source
RES-E	Electricity production by renewable energy sources
s	Second
s.	Sensitised
Si	Silicon
SO_2	Sulfur dioxide
SRMC	Short run marginal cost
STC	Standard Test Conditions
t	Ton or
	Time
T	Full load hours or
	Overall time
tbd	To be defined
TSO	Transmission system operator
TWh	Terawatt hour
U_n	Battery voltage level
US	United States
USD	US-Dollar
v	Velocity, wind speed
V	Volt
VAT	Value Added Tax
VDE	Verband der Elektrotechnik Elektronik Informationstechnik e.V
W	Watt
W_p	Watt peak
y	Year
z	Interest rate

α	Azimuth angle of the PV modules or
	Capital recovery factor
°	Degree
η	Efficiency factor
€	Euro
λ	Lambda
μ	Mu
‘	Minute
%	Percent
π	Pi
∑	Sum

1 Introduction

1.1 Motivation

The decision for writing this topic is influenced by my personnel interest in CEE-countries and especially Croatia. For more than ten years, I have been on site the Dalmatian area and knowing the local energy production facilities and prerequisites. The existing diesel generators in the area of the Kornati national park contrast with the idea of preservation of the biological diversity and ecology. Therefore, this work focuses on the feasibility of a suitable off-grid renewable energy supply and suggests a technology to secure a stable energy production under sustainable and ecological aspects. This would help to preserve the Croatian natural heritage on the one hand and provide an economically applicable solution on the other hand.

1.2 Core objective of work

The core objective of this master thesis is to analyse, if a PV off-grid energy system with battery backup can substitute a diesel generator installed on a Croatian island, where no conventional energy supply is available. On the basis of two reference plants, technical analyses and economical calculations are performed, as well as ecological aspects are investigated.

Based on various studies potential scenarios are designed to resolve the theoretical question, if the grid-parity between the electricity production costs with this PV plant and the conventional household electricity costs will be reached until the year 2030, and how the diesel price will develop in this time span. The gained data is aggregated to attain the potential deployment for such small-scale PV plants, which deliver energy for not grid-connected houses, currently supplied by diesel generators, on islands as well as in remote areas along the Croatian coastal line.

1.3 Citation of main literature

Relevant information about renewable energy technologies, especially for photovoltaic, is provided in current publications of several well-known authors, i.a. Kaltschmitt and Streicher, Quaschning or Wagner. The MSc-lecture script of the Country Module Croatia and Slovenia and a number of publications of Croatian Authorities and Organisations (e.g. EIHP, DZS, HERA, HROTE) back the country-related facts. For the technical analyses and the configuration of the PV reference plant the lecture script of Fechner and the compendium 'Leitfaden Photovoltaische Anlagen' of Haselhuhn et al., published by the German 'Gesellschaft für Sonnenenergie' (DGS) are considered. Current product information and catalogues by Rotek and a publication by Tschöke are perused for the diesel generator design. For the economical considerations the NPV calculation by Wellinger and further evaluation methods by Aussenegg are taken into account. The ecological investigations are based on several publications and the results of the GEMIS-study by the Institute for Applied Ecology. The current market prices for PV, diesel and the household electricity prices are collected from different sources, like EPIA, Photon International, GTZ, EIHP, and are aggregated with expert estimates of i.a. Capros, EWI/Prognos and the IEA to receive future scenarios. The estimated potential of such PV plants is based on the Croatian Census and the gained research results. The complete literature references can be found within the text and in the subsequent reference list.

1.4 Method of approach

At first the various publications were researched for possible renewable energy technologies, the storage possibilities and the country specific facts of Croatia, regarding the energy demand and supply, the legislation and the renewable energy deployment, which are then summarised to provide an overview. For gaining latest information the islands of the Kornati archipelago were visited additionally.

After the theoretical part, a technical assessment for a small-scale PV plant with battery storage under the prevailing conditions (irradiation, loss coefficients, module efficiencies, etc.) at the location in the Kornati national park is performed. Such PV applications mounted on roof tops are suitable for single houses or neighbouring houses in immediate vicinity. Not regarded are large-scale applications, meanwhile available almost up to about 100 MW_p, which are mainly used to provide energy for large cities and require a surface area of multiple soccer fields. A ranking of such plants is listed at the internet page pvresources.com (n.d.). Peak (p) in 'MW_p' means the maximum performance of a solar module under STC. Therefore, the modules have to be tested at 25 °C cell temperature with a solar radiation of 1000 W/m² and an air mass (AM) of 1.50. The dimensionless factor AM classifies the average solar radiation, deflected by the Earth's atmosphere (Zahoransky 2007). Despite the electricity production, solar energy can be used for room heating and warm water preparation. These wide-ranging topics are not covered by this work and require special analyses.

As reference for further comparisons to the small-scale PV plant, a diesel generator, currently the only wide-spread energy technology in this remote area, is assessed. The individual calculation steps and results are listed in subsequent chapters and the appendices. After the plant configuration, the electricity production costs are calculated. For this purpose the current price trends and the current Croatian price levels are investigated. A dynamic investment calculation by a NPV analysis is performed, which clarifies if the investment will be successful after the assumed period. For all calculations a plant lifetime of 20 years is taken into account.

Sensitivity analyses for PV and diesel evaluate the influences of single input parameters on the output parameter NPV and therewith the project's success. Additionally the ecological effects of the electricity production with both technologies are assessed. Based on the gained results the plants are compared with each other and with the Croatian household electricity price.

As a next step, the previous development since the year 2008 of PV, diesel fuel and the household electricity prices are investigated. The evaluation of several studies provides a basis for the scenarios. For each technology a moderate and an improved scenario are assumed and their impacts on the electricity costs (€/kWh) are calculated. Nominal values without the consideration of the yearly inflation are incorporated. Finally the computed trend lines are aggregated to depict if the grid-parity between PV and the household electricity prices is theoretically reached and how the diesel energy costs develop compared to the PV costs.

The gained results are converted for all houses of the Kornati archipelago and on basis of the Croatian Census a potential amount of households is identified, which can benefit from the substitution of the existing diesel generators by small-scale PV-plants. Therefore, the economical and ecological influences are calculated. The shift from the diesel systems to the PV technology contributes to develop towards a sustainable electricity production in Croatia, that is necessary to preserve the Croatian natural heritage.

2 Technologies for renewable electricity production

2.1 Photovoltaic

The term photovoltaic describes the „*direct conversion of light into electrical energy with the help of photovoltaic cells*“. The so-called photovoltaic effect implies the property of special materials (semiconductor materials) to produce electricity out of sun light (Seltmann 2000). As semiconductor materials cadmium telluride (CdTe), cadmium sulphide (CdS), copper indium diselenide (CIS) or copper indium gallium diselenide (CIGS), and most frequently silicon are applied (Haselhuhn et al. 2005).

The photovoltaic effect occurs due to the elemental composition of the material. For example silicon forms a stable crystal lattice as the silicon atoms with four electrons in the outer atom shell (valence electrons) have the intention to join other atoms to reach together eight outer electrons. By adding energy to the system, e.g. by light (photons) or heat, these electrons are shifted to a higher energy level and set free in the crystal lattice. This effect is called intrinsic conductivity, but no electricity is produced up to that point. To generate energy, the crystal lattice has to be contaminated with impurities. This process is known as doping and substances with more (phosphorus) or less (boron) electrons than silicon are utilised. When sun light excites the electrons in the semiconductor material in the solar cells, the released electrons flow through the electrical field from the negatively charged phosphorus-side to the positively charged boron-side. This creates a voltage in the solar cell, which by closing the electrical circuit results in a DC-flow with a stable direction and voltage through the contacts on the front and the back of the cell (Haselhuhn et al. 2005).

DC-current is utilized by specific DC-applications. However, in Central Europe everyday applications require AC, with a voltage of 230 V and a frequency of 50 Hz. Therefore the produced DC is converted by an inverter into a single-phase AC. Larger PV plants produce so much electricity that it is converted to three-phase-AC with 400 V, which can be transported over longer distances in the electricity grid (Antony et al. 2005).

Module technologies

Silicon is the second most common element in the world and appears as quartz or quartz sand. For mono-crystalline modules the sand is molten, cleaned and wrought with the help of a crystal seed in form of an ingot with a diameter of approx. 10 cm (Czochralski-process). The produced ingot has a high purity and is cut into thin slices the so-called wafers (Zahoransky 2007).

Poly-crystalline silicon is cast in forms and cut afterwards into wafers. With this production method several crystals develop in the cell because of higher impurities, but the effort for production is less than for mono-crystalline (Zahoransky 2007). Another form of poly-crystalline cells gets ribbon pulled. In this process, a thin-film is pulled out of the silicon melt and cut afterwards by a laser into single cells. This production method avoids high material losses through sawing the silicon block into wafers and leads therefore to an important cost reduction (Haselhuhn et al. 2005).

The mono- and poly-crystalline wafers are doped with boron and afterwards with phosphorus in a diffusion furnace. Subsequent, an anti-reflective coating is necessary to avoid loss of sun radiation. With a screen printing process a small grid on the front side and contacts on the back side are printed and baked afterwards. Therewith the solar cell is completed (Haselhuhn et al. 2005). To form a solar module, an array of solar cells is soldered, placed between plastic films on a glass plate and sealed. Some producers place the cell array between two glass plates and encapsulated them with casting resin. To enhance the stiffness and secure the glass plates, an aluminium frame is fixed around the module. Finally, a socket or a waterproof insulated cable is mounted at the back of the module (Seltmann 2000).

Besides crystalline silicon providing stiff wafer plates, amorphous silicon or any of the above mentioned semiconductor materials (CdTe, CdS, CIS, CIGS) can be applied on a substrate by deposition as a thin-film (layer thickness of a few micrometres) out of the gaseous phase. The commonly deployed substrates are glass plates (Zahoransky 2007). The surface of the modules is cut into thin stripes by a laser. This production method allows the production of full modules at variable application sizes. The module is encapsulated with another glass plate and casting resin. A frame is mounted and finally the socket or connection cable is installed. The production costs are cheaper compared to crystalline modules due to the lower material requirement (only 1 to 2 % of silicon) and the faster production processes (Seltmann 2000).

EPIA (2011a), Neubarth et al. (2009), Wagemann and Eschrich (2010) and Quaschning (2009) et al. provide information about further poly-crystalline production methods (EFG – edge-defined film-fed growth, string ribbon pulled or APex cells), different forms of mono-crystalline structures (spheric or sliver cells), rigid or flexible thin-film modules with different semiconductor materials and silicon based cells with different layer thicknesses (amorphous and micro-crystalline silicon). Specified therein are also dye-sensitised cells working with a liquid electrolyte, hybrid cells (HIT – heterojunction with intrinsic thin layer) consisting of crystalline and thin-film structures as well as concentrator cells with different semiconductor layers (multi-junction) and special optic devices to concentrate the incident sun radiation.

Efficiency

Table 1 highlights the efficiency rates of different commercial PV technologies. Thin-film modules are produced as complete modules, meanwhile crystalline and multi-junction technologies consist of several cells, which are assembled to modules and hence reach lower overall module efficiency values. Furthermore, the area requirement (m²) per kW is listed (EPIA 2010).

Table 1: Commercial module efficiency
Source: EPIA (2011a)

<table>
<tr><th colspan="9">Commercial module efficency</th></tr>
<tr><td>Technology</td><td colspan="5">Thin Film</td><td colspan="2">Crystalline Silicon</td><td>CPV</td></tr>
<tr><td></td><td>(a-Si)</td><td>(CdTE)</td><td>CI(G)S</td><td>a-Si/uc-Si</td><td>Dye s. cells</td><td>Mono</td><td>Multi</td><td>III-V Multi-junction</td></tr>
<tr><td>Cell efficiency</td><td rowspan="2">4-8 %</td><td rowspan="2">10-11 %</td><td rowspan="2">7-12 %</td><td rowspan="2">7-9 %</td><td rowspan="2">2-4 %</td><td>16-22 %</td><td>14-18 %</td><td>30-38 %</td></tr>
<tr><td>Module efficiency</td><td>13-19 %</td><td>11-15 %</td><td>~ 25 %</td></tr>
<tr><td>Area needed per kW (for modules)</td><td>~ 15 m²</td><td>~ 10 m²</td><td>~ 10 m²</td><td>~ 12 m²</td><td></td><td>~ 7 m²</td><td>~ 8 m²</td><td></td></tr>
</table>

Currently, the efficiency of crystalline silicon modules reaches max. 19 %, while thin-film technologies attain only 12 %. Among the thin-film technologies the dye-sensitised cells are just emerging at the market providing low efficiency values yet; because of lacking long-term data the area demand per kW of these cells is still missing. Multi-junction cells „*are made from very small amounts of highly efficient, but expensive, semi-conducting PV material*" and „*have precise and accurate sets of lenses*", which made the large-scale deployment expensive and yet not economically viable (EPIA 2011a).

The losses during the energy conversion are caused by diverse factors. Haselhuhn et al. (2005) deploy a module efficiency degree of 13 % and mention the following deductions:

„*100.00 % irradiated solar energy*

- *3.00 % reflection and shading caused by front contacts*
- *23.00 % too low photon-energy in long wavelength radiation*
- *32.00 % too high photon-energy in short wavelength radiation*
- *8.50 % recombination losses*
- *20.00 % potential difference in the cell, particularly in the space charge region*
- *0.50 % series resistance (ohmic losses)*"

13.00 % of the irradiated solar energy can be converted into electrical energy

It has to be considered that the efficiency grades improve with ongoing research and development activities of the PV industry continuously. High cell efficiency improvements could be obtained by developing materials which are more sensitive to high and low photon-energy.

Furthermore, the reflection from the surface and the shading by the contacts have to be minimised by an optimised cell design. More difficult to address are the other sources for a loss of efficiency. Thereby, recombination means the effect of an electron not reaching the contact and joining an atom with a missing valence electron instead. Accordingly, the occupied charge carrier cannot contribute to the electricity production anymore (Haselhuhn et al. 2005). The potential difference, responsible for about 20 % of the efficiency losses, defines a voltage difference between two different points (VDE 2008), in this case between the different cell layers. The space charge region contains some surplus electrons, which were diffused from the negative layer into the positively charged layer during the doping-process. Finally, small losses due to series resistance occur because parts of the energy are absorbed and converted into heat (Haselhuhn et al. 2005).

Furthermore, differences between cell, module and system efficiency degree arise. The efficiency of the module is lower than those of the cell simply because not the full surface area of the module is covered with cells. The system efficiency degree decreases additionally as different losses by the cabling and inverter occur (SMA Solar Technology AG, n.d.). The inverter changes the direct current into alternating current with an efficiency of 90 to 97 %, which is dependent on the performance of the PV modules under different weather conditions (Solarstromerzeugung.de n.d.).

Yield influencing factors

In general, PV systems operate fully automatic, so technical problems happen only infrequently. For a high energy yield and an error-free operation of PV systems several factors have to be considered (Haselhuhn et al. 2005 and Fechner 2010). The prevailing conditions for the reference site are analysed in Chapter 4.

- *Solar radiation*: The intensity of solar radiation is determined by the distance between the Earth and the sun, the Earth's rotation and the deflection caused by the atmosphere. An average value of 1,367 W/m² is stated as solar constant outside of the Earth's atmosphere. Due to reflection and absorption of the atmosphere and scattering for example through pollution, the value is shortened to approx. 1,000 W/m². The sum of the annual solar radiation (kWh/m²), which varies strongly with the geographic region, is taken as a basis for yield calculations.

- *Direct and diffuse radiation*: The solar radiation consists of direct light from the sun and scattered light. The scattering depends on the solar altitude according to the time of the day, the season, the cloud conditions and the surrounding area, if the PV system is inclined.
- *Ground reflection*: Sloped PV systems are additively influenced by the properties of the nearby ground, in the calculations this effect is quantified with the so-called albedo value. For example, light surrounding areas (higher albedo value) provide more diffuse radiation by reflection than darker environments (lower value). Exact data is given by Haselhuhn et al. (2005).
- *Solar altitude and spectrum*: The solar elevation angle is measured from the horizontal and varies over the day and with the seasons. For example in winter, the sun light falls in a flat angle on the Earth and the light is more scattered through the atmosphere. Therefore the AM-factor is introduced, which specifies the travel distance of the sunlight through the Earth's atmosphere normalised by the perpendicular thickness of the atmosphere. For instance, an AM of 1, corresponds to an angle of 90°, which occurs when the sun reaches the equator at the noon of the spring or autumn equinox. To maximise the PV energy yield, solar systems in the Northern hemisphere should be orientated southwards (Azimuth 0°).
- *Inclination*: The solar radiation on a surface perpendicular orientated to the sun light's angle of incidence is always higher than the solar radiation on a horizontally orientated surface. Additionally, an inclination of min. 25 to 30° leads automatically to a cleaning effect by the rain.
- *Temperature*: The electrical output of the solar modules decreases with increasing temperature, so a well considered mounting with enough air supply, for convective cooling, especially on roof tops or at building integrated systems, is necessary.
- *Connection of the cells and modules*: The interconnection of single cells in the module or among modules is done either serial or parallel. For the serial connection the voltage will increase, while the current remains constant. On the opposite, for the parallel connection the voltage does not change while the current will increase.
- *Mismatch-losses*: Connected modules adapt their performance to the worst module. Due to production related variations, a sorting of the modules according to their performance is recommended.

- *Shadowing effects*: The shading by trees, parts of the building on which the PV system is installed or other houses must be avoided, because the connected modules always adjust to the performance of the worst.
- *Hot spot effect*: A partly shadowing of the modules can force the cell to use energy, instead of producing it. The cells heat up and by doing so they maybe destroy themselves. The integration of bypass-diodes in the module can help to prevent such breakdowns.
- *Static*: The weight of the modules and of the mounting racks has to be considered with respect to the strength of the particular base (roofs, building parts and ground).
- *Further aspects* like expansion joints for dealing with increasing temperature, UV-resistance of the cables, high-quality DC-wiring and the implementation of a DC-switch, to separate the inverter, have to be taken into account.

Metrological sun radiation data gives first hints towards a suitable area, but the consideration for a PV project has always to be done individually for each location. Therefore key performance indicators, like the 'performance ratio' (PR) and the 'final yield' (FY) are calculated. The PR should lead to a figure of 70 to 85 % and is the quotient of the real energy yield, influenced by mitigating factors like shading, and the ideal energy yield, composed of the plant size, the module efficiency degree and the annual global radiation. The final yield states the full load hours of the system and is calculated by dividing the real energy yield by the nominal power of the PV system (World Energy Council 2010, Haselhuhn et al. 2005). The calculations for the reference plant are stated in Chapter 4.

Classification of PV systems

Suggested by Haselhuhn et al. (2005) PV systems can be classified into grid-connected and stand-alone systems. Stand-alone systems or so-called off-grid systems are installed, if the connection from remote areas to the public electricity grid is too costly. As described in Chapter 2.1., stand-alone systems without storage work only if the electrical circuit is closed. If no electric consumer is activated, no current will flow. Most of the stand-alone systems are equipped with storages because the moment of energy production (during the day) mostly differs from the moment of the energy consumption.

Already existing in everyday life are small applications such as solar chargers for calculators or appliances like garden lighting or PV systems for parking ticket vending machines, which can store energy for short intervals (Haselhuhn et al. 2005). Stand-alone systems, either DC- or AC-systems, are able to energise larger consumers like desalination systems, households or small villages. The only difference between these systems is the necessity of the implementation of an inverter in case of AC-power supply (Antony et al. 2005).

Hybrid-systems consist of an additional energy source to support the PV system. The completion with a wind turbine or diesel generator secures the electricity supply twenty-four-seven, when the sun is not shining. In combination with a cogeneration engine heat is produced additionally (Haselhuhn et al. 2005). The wide-ranging topic of hybrid-systems is not further discussed because it goes beyond the scope of this work.

Grid-connected systems deliver the produced energy directly to the electricity grid, where the nearest electric consumer uses it. If more energy is available than the load requires, the electricity will flow through the grid to the next consumer, and so on. PV systems that are connected to the public grid via the house grid supply the surplus energy, which is not consumed within the household, to the grid (Seltmann 2000).

PV system components

An off-grid PV system consists of several PV modules or arrays (multiple PV modules on a mounting frame are connected in series or parallel) which are connected via a DC-cabling and a charge controller with the battery and the loads, respectively. The charge controller manages the charging activities of the battery to secure a high availability and longer service life. More information about storage possibilities is provided in Chapter 2.6. If AC-devices are applied, an inverter and AC-cabling has to be installed. The inverter converts the DC-power from the PV plant into the required AC-power. For grid-connected PV systems additional technical equipment, like a combiner/conjunction box with protective equipment, a DC main disconnect/isolator switch and a meter cupboard with power distribution system, supply and feed meter, and electricity connection, conforming to the energy utilities' standards has to be installed (Haselhuhn et al. 2005).

PV plants can be integrated in the roof or facade, mounted on sloping roofs or deployed on flat roofs or free standing on the ground. Further information about these methods and the required mounting components is documented in Seltmann (2000).

The modules can be firmly fixed or adjusted to the sun's position. So-called tracker-systems move the PV modules with the sun's altitude to maximise the share of direct radiation and increase the yield (20 to 30 % compared with fixed systems). These applications are recommended for areas with a high share of direct radiation e.g. in Spain or Northern Africa since otherwise the yields cannot compensate the additive investment, operation and maintenance cost (Haselhuhn et al. 2005).

2.2 Wind energy

Wind arises through differences of temperature and pressure in the atmosphere. These thermal compensatory movements occur when the solar radiation heats up the Earth's surface by several degrees. The heated air begins to rise in the atmosphere because of lower density. This pressure difference causes the air masses from higher levels or from different regions to shift in order to equalise the pressure. The atmosphere consists of several layers, where the wind is influenced differently. The boundary layer surrounds the Earth and reaches a height of approx. one kilometre, varying by atmospheric and pressure conditions, and is divided into the lower 'Prandtl layer' or so-called friction at the Earth's surface and the 'Ekman layer' at above approx. 100 m height. In the Prantdl layer the wind is depending on the surface roughness and on obstacles like buildings. Furthermore, the orography (shape) of the land affects the wind. At elevated areas such as hills or mountain tops the wind speed is more intense because the flowing air masses are compressed through the natural obstacle. In these areas the energy exploitation is recommended, contrary to the valleys at lee side, where the wind speed decreases (Krenn 2010a).

The wind speeds at different heights (vertical wind profile) are calculated with the logarithmic wind law. The calculation method is described by Häckel (2008). Krenn (2010a) points out that according to the logarithmic wind law the wind speed is increasing with the height. This implies that the hub height of the wind turbine should be as high as possible. For example, if the wind speed doubles, the energy will increase by a factor of eight. As a rule of thumb, one metre of additional tower height will increase the yield of the wind power plant by approx. one percent (BWE 2010).

The theoretical wind power (P_{th}) is calculated with the formula $P_{th} = P/2 \cdot A \cdot v^3$. The factor 'P' defines the density of air (1.23 kg/m² at atmospheric pressure and 15 °C) and is depending on air pressure and temperature. The air density decreases by approx. 1 % per 100 m above sea level. 'A' terms the rotor swept area that is orientated perpendicular to the wind and that is calculated using the formula for the circle area ($A = r^2 \cdot \pi$). 'v' represents the wind speed (m/s) (Krenn 2010a).

The wind energy is converted into electrical energy by three major turbine types, which operate grid-connected or stand-alone providing the electricity for a certain consumer (Twidell and Weir 2006).

Vertical-axis turbines utilise wind from any direction without adjustment. Anemometers for wind measurements work with this principle. Twidell and Weir (2006) specify the Savonius, the Darrieus, the Musgrove and the Evans rotor as vertical-axis turbines, which use the lift or drag force to produce electrical energy after being started by a motor. The gear boxes and generators are located on the ground. Vertical-axis turbines are not implemented as standard because of fatigue failures caused by natural resonances in structures and a complex tower support.

Concentrators represent another rotor system, which funnels or concentrates the intercepted wind from the outside of the rotor section into the turbine. Systems with funnel shapes and deflectors, which are fixed statically around the turbine to draw wind into the rotor, are not used for commercial machines on the contrary to blade tips. These special blade designs or adaptations draw the air from outside of the cross-section into the rotor area (Twidell and Weir 2006).

Horizontal-axis turbines use the aerodynamic lift as driving force similar to airplane wings and are equipped with one or more aerodynamically optimised rotor blades mounted on a horizontal rotation axis. The flow energy from the wind turns the blades and this rotational movement is channelled to the axle. Most common are two- and three-bladed turbines, whereby three-bladed ones show the best performances in electricity operation and run quieter than the two-bladed rotors.

As the wind speed is fluctuating steadily, regulations for the rotational speed or adjusting mechanisms for the rotor blades are implemented to stabilise the energy production (Zahoransky 2009, Twidell and Weir 2006 and Krenn 2010b and 2010c). When the wind energy turns the blades, fixed at the rotor hub, mechanical energy is created. This is transferred over the main axis with bearings to the gear box, to create the required rotational speed for the generator (1,200 to 1,800 rounds per minute) to produce electrical energy. Recently gearless large-scale wind power plants with multi-pole slow-speed ring generators have been developed, at which the rotational speed of the rotor corresponds to the speed of the generator. The costs for these turbines are significantly higher, but no further expenses for the exchange of the gearbox have to be considered (Krenn 2010c). Krill (2010) states that over 20 years lifetime of the turbine on average one gear box change will be necessary. Finally the generator transforms the produced energy into AC with the required voltage and frequency. More information about the working principles of generators is explained by Krenn (2010c).

2.3 Hydro power

The energy production of hydro power plants depends on two factors, the rated head and the rated discharge. The head is the difference in height between the water levels of two river sections. The potential energy of the water between these sections is converted by a turbine, situated at the lower river section. The rated discharge is a certain amount of water (m^3/s) flowing through the turbine producing electricity. The configuration of the turbine has to be adjusted to the natural variation of the flow regime. Therefore, long-term discharge measurements are necessary or the river discharge available over the year has to be calculated, considering precipitation, evapotranspiration, drainage, catchment areas and the surface geology (ESHA 2004).

Hydro power plants can be divided by their operation mode (run-of-river or storage plant), their head and their building structure (weir, diversion type) (Pelikan 2010, ESHA 2004 and Giesecke and Mosonyi 2009). Small hydro power plants up to 10 MW nominal power are mostly run-of-river types as a result of the available water flow and head. A concentration of head by construction of weirs, diversions or by lowering the tail water is necessary to make a certain head exploitable.

The powerhouse with the turbine is situated at the point of concentration (Pelikan 2010 and ESHA 2004). In contrast, most large hydro power plants are storage plants, which need a high dam closing off a whole valley cross section, artificially creating a storage lake. Storage plants are discussed in the next section.

The ESHA (2004) distinguishes three head classes, low head (2 to 30 m), medium head (30 to 100 m) and high head (100 m and more). In dependence of the topography high head plants use either weirs or high dams to impound the water in front of the inlet structure equipped with a trash rack. From there the water is supplied by a pressure pipe or a penstock to the turbine. Penstocks are really expensive so a diversion system can be reasonable to bridge the distance. Diversion structures consist of a low-slope headrace channel, in which the water runs alongside the river to a pressure intake or fore bay and further through a short penstock to the turbine. Behind the turbine the water is discharged back to the river via a tailrace channel (ESHA 2004).

Low head plants are usually built along river valleys. Two construction types are possible; the creation of weirs, also referred to as spillways, with an integrated water intake or the diversion method. Weirs are fixed structures in the river bed, which create backwater areas and increase the water head available for the turbine in the particular river cross section. The water is led through a trash rack to an intake into the turbine, the rest of the water flows over the construction. Behind the weirs so-called energy dissipating structures, such as stilling basins, are necessary to avoid severe erosion caused by high flow velocities and water turbulences (ESHA 2004 and Krauß 2010).

For low head diversion hydro power plants also weirs or spillways are used to divert part of the available water. The water runs into a separate channel of variable length, sometimes equipped with a sediment trap, where sand and stones are captured. The clean water enters the turbine through supply works and flows via a tailrace channel back to the river. An erosion of the turbine blades caused by gravel or sand must be avoided as the turbine’s efficiency and the power generation will be reduced (Drobir 2010). Therefore, two types of intake and desilting structures can be constructed. The Tyrolean weir with desilter is implemented for flows up to 5 m³/s. At larger flows side intakes with desilter are built. More information about these structures is given by Krauß (2010) and Drobir (2010).

The turbine type is chosen depending on the prevailing site conditions (head and discharge). Three main categories of turbines are available (Zahoransky 2009, ESHA 2004 and Panhauser 2010):

- Axial turbines or so-called Kaplan turbines, working at low head and with large discharge, are consequently suitable for large run-of-river installations. The flow of water is distributed by fixed or adjustable guide-vanes and turns the adjustable runner blades (reaction turbine). If the guide-vanes and the runner blades are variable, the turbine is called double-regulated and hence will react on different flow conditions with high efficiency.
- Francis turbines with a simple equipment design are working with medium heads up to approx. 100 m and medium discharge. The discharge is controlled by a distributor with adjustable guide-vanes, which adapts the inlet angle of the flow to the fixed angle of the runner blades (reaction turbine).
- Pelton turbines are specialised on small discharge and high heads. These turbines are easy to regulate and work with good efficiency rates. The large heads lead to high-speed water jets, which strike the buckets mounted on the outside of the runner (impulse turbine).

For exceeding conditions custom-made turbines are necessary. For small-scale plants less than 100 kW Panhauser (2010) recommends cross-flow turbines, momentum water-wheels or the Archimedic Screw. These technologies are not further investigated in this work. Detailed specifications about the turbines offer i.a. Zahoransky (2009), ESHA (2004) and Vinogg and Elstad (2003).

Turbines, particularly low-head ones, work at a low rotational speed of up to 400 rounds per minute. A speed increaser is installed ahead of the generator to produce a frequency of 50 Hz according to the net requirements. Nowadays, synchronous, asynchronous and permanent magnetic AC-generators (similar to wind turbines) are used. More information about speed increasers, generators and further technical equipment, such as turbine control devices, switchgears and automatic controls, provide Zahoransky (2009), Panhauser (2010) and ESHA (2004).

The turbines, the generator and the electrical equipment are mounted in a power house. When the turbines are situated below the water level (together with the generator in a waterproof unit) no conventional power house for the switchgear and the control equipment is necessary. Suitable cooling possibilities, like air shafts or vans, have to be installed to remove the heat produced by the various plant components (ESHA 2004).

Storage plants

The output of run-of-river plants varies only gradually from day to day, but these plants are not designed for medium- or long-term storage of water (BHA 2005). For a stable energy production as a base load power plant or to serve during peak loads, only large run-of-river installations and hydro power plants with dams are suitable. Therefore rivers are impounded during the rainy season up to a height of more than 100 m to form a large reservoir, which can be emptied throughout the dry season or quickly for rapidly meeting the peak electricity demand. Currently, the plant 'Three Gorges Dam' in China, with 18,200 MW installed capacity, and the plant Itaipú, at the boarder between Paraguay and Brazil, with 12,600 MW installed capacity, are the two largest storage hydro power plants in the world (Zahoransky 2009).

Another energy storage system is a pumped storage hydro power plant. Contrary to the conventional storage power plants, where the utilised water is supplied by the natural flow, these plants work with a constant amount of water in two basins with different altitudes above sea level. The electrical energy is stored as potential energy in the water of the upper reservoir. An electric motor impels a pump, which conveys the water against the gravitational force from the lower to the upper basin. If energy is needed, the water will be supplied by a pressure pipe downwards into a turbine, which turns a generator to produce electrical energy. The amount of storable energy is depending on the volume of the basins and the drop height between the two levels. Appropriate conditions can be found in mountainous regions and require well developed high-voltage power lines to transport the exceeding and produced energy from and to the pumped storage plant. Approx. 280 plants exist worldwide at the moment. Due to the massive environmental impact of such large-scale projects, the development of new plants is limited. Therefore, existing plants are improved or subterraneous plants are built to reduce the environmental interference. The conversion efficiency ranges between 70 and 80 % (Neupert 2009).

Other hydro power concepts

The difference of potential induced by high and low tide is utilized by tidal power plants. The high tide pushes water into an upper basin and in the low tide the stored water runs through a turbine back into a lower basin and produces energy by impelling the turbine. Wave power plants utilize waves, which rise when wind energy hits a water surface. The waves move floats or underwater devices and this movement is transferred as mechanical energy to a generator. Ocean thermal power plants utilize different energy gradients in the water. These plants work like a heat exchanger and use the temperature difference between the warm ocean's surface and the colder water in depths of 500 to 1,000 metres (Zahoransky 2009). Another source for energy conversion with water is osmosis pressure, when two fluids with a different salinity are separated by a semi-permeable membrane. For example, when fresh water from a river runs into the salty ocean, the water with the lower salt content tends to dilute the higher salt concentration and therewith a pressure difference at the membrane arises, which can be converted into electrical energy (Statkraft n.d.).

2.4 Biomass

Hofbauer (2009a) gives the following definition „*Biomass - includes all kinds of materials that were directly or indirectly derived not too long ago from contemporary photosynthesis reactions, such as vegetal matter and its derivatives: e.g. wood and wood wastes, fast-growing trees and plants, agricultural crops and wastes, livestock operation residues, animals and animal wastes, aquatic plants, and municipal and industrial wastes*." Two conversion methods for biomass into electrical energy are feasible; the thermal conversion by pyrolysis, combustion or gasification, and the production of biogas, which is brought into a combustion process in a second step.

The thermal conversion types require dry high-carbon biomass and differ by the presence of oxygen, expressed with the figure Lambda λ. The combustion process works at temperatures of more than 800 °C with a sufficient amount of air or oxygen ($\lambda >= 1$), to guarantee a complete combustion. The product of the combustion process is flue gas and water. The gasification takes place at more than 700 °C and with less oxygen ($0 < \lambda < 1$), producing a usable gas.

This gas is cleaned and utilized in a combustion process afterwards or upgraded for other applications, e.g. the injection into the gas grid. At the last process, the pyrolysis, organic matter is converted at the absence of oxygen (ℷ = 0) into different products. Mainly liquids and in smaller fractions charcoal and gases are produced, therefore this process is not further regarded (Zahoransky 2009, Hofbauer 2009a).

The thermal combustion works with different combustor technologies, the grate combustors with a fixed bed (underfeed stocker, travelling grate, inclined or horizontally moving grate), the fluidized bed combustors (stationary or circulating) and pulverized biomass combustors, which use a pneumatic transport of the biomass particles. The gasification of biomass has been under development during the last three decades all over Europe und different facilities were implemented. The gasification process is done in small-scale range up to 5 MW in fixed bed (up-draft, down-draft) gasifiers. For a large-scale deployment of 10 up to more than 100 MW fluidised bed (bubbling, circulating or dual) or entrained flow gasifiers are implemented. More about these plant technologies and their features is mentioned by Hofbauer (2009b).

Biogas is obtained during the digestion of wet organic matter, like manure, sewage sludge or waste materials (Wellinger 2009) in airtight, thermally insulated fermenters. These feedstocks contain proteins, fats and carbohydrates such as starch and cellulose which can be converted into methane. Not degradable by anaerobic bacteria is woody biomass as it is made of lignin. Methane bacteria need substrate with at least 50 % water content and a minimum temperature of 25 °C (Eder and Schulz 2007). Additional process parameters according to Wellinger (2009) and Eder and Schulz (2007) are:

- The concentration of the individual substances, like ammonia and volatile fatty acids which inhibit the methanogenesis
- The hydraulic retention time, which defines the average time the substrate remains in the digester
- The loading rate of the digester, this means how much substrate is fed daily per m³ of the digester. Too much substrate can influence the biological process negatively.

The process steps of the anaerobic decomposition are hydrolysis, acidogenesis, acetogenesis and methanogenesis; for detailed information compare Eder and Schulz (2007). The biogas has a methane content of 55 to 85 % (Zahoransky 2009) and has to be cleaned to remove inorganic or organic compounds like hydrogen sulphide or siloxanes in the gas which cause corrosion. For an upgrade to synthesis gas, which is injected into the gas grid, or to vehicle fuel further process steps are necessary (compare Wellinger 2009 and IEA Bioenergy Task 37 n.d.).

Energy conversion

In the following section the common conversion technologies are discussed. Fuel cells, Sterling engines and micro turbines are not further regarded as their development is still in progress. The produced flue gas and the heat from the combustion process are utilised in a CHP-process with steam engines and steam turbines to produce electricity and heat. This takes place in closed thermal cycles, which are characterised by a separate heat exchanger between combustion and power generation to transfer the heat from the flue gas to the power engine. Therefore cleaned water is evaporated by the produced heat and expands. The energy contained in the steam runs as kinetic energy the steam engines and steam turbines, which turn a generator. The produced mechanical energy is transferred by the generator into electrical energy. The steam condenses and liquefies back into water afterwards and is brought back to the evaporation again. This condensing process is called Clausius-Rankine-Cycle. When instead of water another media, like Butan or Pentan, are used, the process is named Organic-Rankine-Cycle (ORC) (Hofbauer 2009b, Zahoransky 2009).

In open cycles gaseous or liquid fuels are burned directly inside the combustion engines or in a combustion chamber. The arising fuel gas impels gas turbines or combined cycle gas turbines (CCGT). Both last-named technologies are used for large-scale projects with an electrical output from 1 to approx. 300 MW. The plants consist of a compressor that concentrates the air, a burning chamber and a gas turbine. The compressor and the turbine are connected by one driving shaft. The compacted air flows into the burning chamber, is mixed with a gaseous or liquid fuel and ignites. The hot flue gas (temperatures of approx. 1,250 °C) expands in the turbine and impels it. The rotation energy of the turbine is converted in a linked generator into electricity. Due to the high temperatures the turbine blades are manufactured from ceramic or other high temperature resisting materials. After the expansion the flue gas is released into the atmosphere where it cools down. As a result of the high air ratio in the burning chamber the fuel is burned completely, which keeps the emissions low (Zahoransky 2007). The CCGT-plant with an electrical output from approx. 50 up to more than 1,000 MW is a combination of a gas and a steam power plant. Existing steam power plants can also be equipped with a gas turbine and a heat recovery boiler. The process works according to the above explained gas turbine cycle but the approx. 500 °C hot flue gas of the gas turbine heats a boiler, where water is evaporated that impels another turbine which is linked to a generator. An additional benefit of the CCGT is that the occurring heat can also be used to heat a district heating net (Zahoransky 2007).

For smaller projects stationary and mobile combustion engines are applied. Common is a cogeneration or so-called CHP-plant that produces electricity and heat. These plants are more economic compared to the electricity production with a normal combustion engine as the produced heat could be sold to an existing district heating net. Scholwin et al. (2009b) explain the principle of CHP-plants as a combustion engine linked to a generator. The engine runs constantly with 1,500 revolutions per minute so that the directly linked generator can provide electricity compatible to the net frequency. Following combustion engine types are applied:

- Gas-Otto-engines
- Gas-Diesel-engines
- Jet ignition engines

Gas-Otto-engines and Gas-Diesel-engines are specially designed for the operation with gas, both working according to the Otto concept without additional ignition oil. The only difference between the two engines is the fuel compression. The minimum content of methane in biogas must exceed 45 % otherwise the engine deactivates itself. If biogas is not available the engine will run with other sorts of gas e.g. natural gas. Jet ignition engines work on the Diesel principle and are modified for gas combustion. The biogas is mixed with air in the combustion chamber and gets ignited by adding ignition oil through an injection system. This oil either consists of diesel oil or heating oil, but the added oil should amount to a maximum of 10 % of the fuel performance (Scholwin et al. 2009b).

2.5 Geothermal

Geothermal energy is an independent energy resource, not subject to climatic conditions, daily variances or seasonal fluctuations (Zahoransky 2009). The utilization ranges from heat for room heating or warm water preparation to the production of energy. The crucial factor for the geothermal potential is the enthalpy or heat content, which denotes the useful work, that can be extracted from a closed thermodynamic system under constant pressure. Low enthalpy fields provide water temperatures of below 100 °C, the medium enthalpy fields delivers water and steam between 100 and 180 °C and fields with high enthalpy deliver even higher temperature (Milics 2010). Valdimarsson (2010) classifies the geothermal fields as follows:

- „*Hot dry rock - no water at all […]*
- *Vapour dominated fields - deliver steam ready for the turbine*
- *Water dominated fields - water flows into the wells, and boils partly*
- *Liquid water - temperature below 100 °C, the fluid contains non-condensable gases and dissolved solids*"

The energy contained in the water in low and medium enthalpy fields is used for heat purposes, which are not further discussed. The fields with vapour, dry steam or high temperature water (> 210 to 220 °C) are suitable for the electricity production. Generally, the temperature increases with the drilling depth (temperature gradient of 0.03 °C/m), but in regions with high geothermal activities this gradient can reach 0.15 °C/m. These areas are located where the continental plates collide. In Europe mainly sedimentary basins are exploited, which do not reach such high enthalpy gradients. The drilling depth depends on the location of the expected reservoir and can reach several thousand metres (Milics 2010).

The design of a geothermal plant for energy production depends on 25 to 30 design parameters, especially on the temperature and the flow amount out of the well. Consequently, the cooling system and the heat exchanger have to be adapted. Heat exchangers are implemented, when too high concentrations of corrosive elements are contained in the geothermal water. Four plant designs are available for the electricity production; the Flash and Double Flash systems are built for direct exploitation. The steam from the Earth's interior turns a turbine and is cooled afterwards to reach the condensation. The so generated water is re-injected through a second well into the ground again. ORC and Kalina systems are constructed if too many corrosive components would damage the plant. The geothermal heat is transferred in a heat exchanger to a working fluid that heats the turbine circuit. The geothermal water is further cooled, condensed and re-injected again (Valdimarsson 2010). More information about these plant technologies provide i.a. Zahoransky (2009), Valdimarsson (2010) and Geothermal-Energy.org (2011).

A still investigated technology is the Hot Dry Rock-method. High geothermal potential is available in hot, arid stone formations in deeper rock layers. The intention is to crack these stone formations by pressing cold water in one well. The water runs through these cracks and heats up. Another well in a distance of approx. 100 to 450 metres is drilled to collect the water for the electricity production. Currently, this method is under investigation and inappropriate handling can cause earthquakes (Basel, Switzerland in the year 2006) as the cracking produces a high tension in the stone formations (Zahoransky 2009).

2.6 Excursus: Battery storage systems

Battery storage systems are especially deployed for energy production plants with fluctuating output (e.g. wind, PV) without other storage possibilities like e.g. biogas plants to deliver electricity at a certain time, when no or not enough energy is produced (Scholwin et al. 2009a, Haselhuhn et al. 2005). At the moment lead acid batteries (accumulators) are utilised for small-scale PV off-grid systems as they provide the best answer with respect to price and durability (Messenger and Ventre 2010). Further alternative systems, like electric, electromagnetic, mechanical and chemical storage possibilities are not investigated in this work. For more information compare i.a. studies of the Fraunhofer Institute (Neupert et al. 2009). The deployment of lead acid batteries ranges from 0.10 to 100 kWh, selectively up to the MWh-scale. The battery capacity is stated in ampere hours (Ah) and defines the possible electricity amount which can be extracted. It is determined by the discharge current demand (W), the duration of discharge (h) and the system's voltage level (V). Lead acid batteries consist of *„several single cells with a nominal voltage of* 2 V", which are serially connected and embedded in a housing. Conventionally used are accumulators with 6 or 12 cells (voltage of 12 / 24 V).

For bigger systems the batteries can be connected in series or parallel to achieve the required system voltage and capacity (Haselhuhn et al. 2005). The calculations for the PV reference project are performed in Chapter 4.6. The batteries contain two electrodes with different polarity and the electrolyte-fluid diluted sulphuric acid (H_2SO_4). The electrodes consist of grid-like lead plates and active material and are isolated by separators. When a consumer needs electricity, electrons flow from the load to the negative and onwards to the positive pole. This causes a chemical reaction between the electrodes and the electrolyte-fluid. The electrodes react to lead (negatively charged) and lead dioxide (positively charged). The diluted sulphuric acid is reduced through the chemical reaction and the concentration of the acid decreases. Therefore the fluid content has to be monitored regularly and refilled with distilled water if necessary (Haselhuhn et al. 2005). Fechner (2010) suggests every six month regular inspections of e.g. the electrolyte-level and the cell-voltage and points out that temperatures between -20 °C and +40 °C and a moisture content of max. 95 % have to be secured to guarantee a faultless operation.

When the battery is charged again, the electrons flow back from the positive to the negative pole and the previous chemical reaction is nearly completely reversed. Small amounts of lead sulphate are not converted back and the capacity of the battery is slightly reduced. The quantity of charge and discharge cycles varies with the type of accumulator and the discharge rate between 2,000 and over 5,000 times. Different effects like corrosion or the accumulation of mud mitigate the performance. More information about these influences can be found in Haselhuhn et al. (2005). The rate of discharge influences the lifetime perspectives of the battery additionally. If the maximum discharge rate gets purposely or inadvertently below the producer's recommendation value (deep discharge), the lifetime of the accumulator will be shortened drastically. More information concerning this topic is provided by Messenger and Ventre (2010). Haselhuhn et al. (2005) state the following types of lead accumulators, which are distinguished by the employed electrodes and electrolyte-fluids:

Flat plate lead batteries with liquid electrolyte: This is the most frequently applied accumulator, used as car battery and therewith cost-effective. Thicker electrode plates must be installed for the combination with a PV system. Additionally, a charge controller is necessary to avoid a discharging of more than 50 % or an overloading to enhance the lifetime of the battery (3 to 8 years).

Lead gel batteries: The functioning of the accumulator is based on the same principle as lead batteries with liquid electrolyte. The only difference is the gelled electrolyte, which improves the performance of the battery. The benefits are for example a decrease in the formation of lead sulphate, the avoidance of gas leaks and that no maintenance is necessary. Gel batteries have a longer lifetime, but are more expensive than accumulators with liquid electrolyte. To ensure a secure and perennial operation a charge controller is necessary.

Stationary clad plate accumulators: Such large-scale batteries have been working for decades as emergency generators. They secure the energy supply, e.g. for one house, over a long-time period of 15 to 20 years. The clad plates encase the liquid or gelled electrolyte. When gel is applied the operation is maintenance-free. In the case of liquid electrolyte, regular controls and refilling are essential. A critical factor is the high weight and volume of these accumulators and their two- or threefold price compared to other accumulators of this size.

Block board batteries: These accumulators are also stationary placed and work with liquid electrolyte. A positively charged block board and a negatively charged flat plate function as electrodes. Block board batteries feature a long-life cycle and low maintenance effort (every 3 to 5 years).

2.7 Excursus: Diesel generators

Diesel generators, as stationary or mobile devices, are widespread in operation all over the world. The application ranges from car, truck or boat engines to the production of energy as cogeneration unit or as emergency generators. The working principle of the diesel generator is similar to those of an Otto-engine with the difference that the diesel engine has no ignition plug and therefore higher temperatures than in Otto-engines have to be generated. In the first conversion step air is compacted in a piston, as a result the temperature rises. Then fine diesel particles are injected, which are immediately ignited as the air temperature is higher than the ignition temperature of the diesel. The ignition of the diesel leads to a further release of heat and an explosive increase of the pressure. The pressure starts a mechanical movement of the piston, the fuel gas is released and afterwards the process is repeated, when fresh air is absorbed again (Zahoransky 2009).

3 Renewable energies in Croatia

The current energy production in Croatia is highly import-dependent and fossil fuel based. In the year 2009 the primary energy supply amounted to 406.92 PJ, which represents the pre-war level of the year 1990. The domestic production summed up to 211.64 PJ, thereof 118.43 PJ, mainly liquid fuels and natural gas, were exported. Consequently the deficit amount of 305.37 PJ had to be imported, mostly consisting of liquid fuels (73 %), followed by natural gas, electricity and coal. The remaining difference was caused by stock changes. The overall primary energy supply had the following composition in the year 2009 and is shown in Table 2 (EIHP 2011).

Table 2: Primary energy supply in Croatia in 2009
Source: EIHP (2011)

Primary energy supply 2009		
Fuel	**PJ**	**%**
Coal, coke	21.24	5.20
Liquid fuels	181.46	44.60
Natural gas	102.15	25.10
Hydropower	65.77	16.20
Other RES	15.84	3.90
Electrcitiy	20.46	5.00
	406.92	100.00

According to Table 2 becomes obvious that three-quarter of the Croatian primary energy supply are fossil fuel based. The production methods for the imported electricity were not defined in the EIHP-report. A satisfactory result is the fact that one fifth of the Croatian primary energy is produced with renewable energies, mainly by large hydro power plants.

From the 406.92 PJ primary energy 65 % (265.92 PJ) are at disposal for the final energy demand. The energy losses during the conversion (72.55 PJ) and the transmission (10.29 PJ) amount to 20 % of the primary energy amount. The remaining energy is utilized for the energy sector’s own consumption (32.97 PJ, 8 %) or non-energy purposes (25.19 PJ, 6 %) (EIHP 2011). The term ‘non-energy use’ denotes the conversion of fossil fuels into products such as lubricants or bitumen (Patel n.d.).

The final energy supply is dominated by liquid fuels (128.74 PJ, 48 %), followed by electricity (55.76 PJ, 21 %) and gaseous fuels (51.40 PJ, 19 %). They are distributed between the industry sector (53.07 PJ, 20 %), the transport sector (89.84 PJ, 34 %) and to the largest extent the other sectors comprising households, services, agriculture and construction (123.01 PJ, 46 %). Detailed information about the consumptions shares is given by EIHP (2011).

Concentrating on the electricity production and therewith on the relating renewable energy sources in Croatia, the figures published by the IEA (2011) for the year 2008 are surveyed. The final electricity quantity amounted to 16,137 GWh in the respective year. From the domestic production of 12,326 GWh about 1,587 GWh were exported. The losses and the energy sector's own consumption amounted to 2,766 GWh. Additionally 8,164 GWh had to be imported. The electricity production by the nuclear power plant Krško, which belongs half to the Slovenian, half to the Croatian state, was not explicitly noted by the IEA. The domestic production was dominated partly by fossil fuels (20 % coal, 20 % gas, 16 % oil) and partly by hydro power (43 %), consisting of small- and large-scale and pump storage plants. The remaining marginal share is attributed to other renewable resources, which are illustrated in Chapter 3.1.

3.1 Current use of RES

Kulišić (2010b) lists the following figures for the electricity generation from RES besides large hydro power in Croatia in the year 2008.

Table 3: Electricity generation from RES in Croatia in 2008
Source: Kulišić (2010b)

Electricity production from RES in 2008		
RES type	**Installed capacity (MW)**	**Electricity generation (GWh)**
Solar	0.08	0.06
Wind	17.15	39.90
Biomass	4.63	21.10
Small hydropower	32.76	94.80
Geothermal	0.00	0.00
	54.62	155.86

Table 3 displays the underdeveloped position of RES in Croatia. Small-scale hydro power plants dominate the RES production, followed by wind and biomass far behind. The PV contribution is very low, reaching only an annual value of 0.06 GWh. No geothermal plants for electricity production are in operation at present. Despite that low contribution, the development of the RES sources during the last years and the convergence of Croatia towards the European Union give hope for an improved RES-deployment in the future. More about the prospective development is denoted in Chapter 3.3.

3.2 Legal requirements

In the year 1997 RES had been mentioned in the national energy programs for the first time, but it lasted until the year 2001 that the energy strategy recognised RES as a national interest. In the following years the first projects were erected and experiences on the side of the owners and the legislation were made. For example, wind parks along one kilometre from the coast and on islands were prohibited (Kulišić 2010b). In 2005 HROTE, the Croatian Energy Market Operator started the organisation of the electricity market. It is responsible for e.g. several analyses and recommendation of improvements, issuing of the Electricity Market Rules, collecting of the RES-E incentive fee and distributing it to the producers, energy balancing and preparation of the day ahead market plan (HROTE n.d.). HROTE is supervised by HERA, the Croatian Energy Regulatory Agency, which is an "*autonomous, independent and non-profit public institution*" which regulates energy activities in the Republic of Croatia (HERA 2010a).

In the year 2007 an extensive legislative package with several RES-E sublaws (Energy Act and Electricity Market Act) was passed. All respective laws are provided online by HROTE (www.hrote.hr) or aggregated by Schoenherr Energy (2010). Therein regulated are i.a. (Kulišić 2010b):

- A minimum share (5.80 %) of incentivised electricity production from RES in the year 2010
- A tariff system for the different electricity production methods
- The incentive fees
- An ordinance in acquiring the status of an eligible electricity producer.

The last measure was taken to gain a better oversight and control of the projects as limitations, like technical regulations set by the TSO, restrict the expansion of RES. The tariff system contains regulations about the promoted types of electricity production, size regulations or utilised raw materials (biomass, biogas). Kulišić (2010b) offers the feed-in tariffs for the year 2010 in Table 4.

Table 4: Croatian RES feed-in tariffs in 2010
Source: Kulišić (2010b)

Type of PP		≤ 1 MW		> 1 MW	
		Kn	**€c**	**Kn**	**€c**
Solar	≤ 10 kW	3.77	51.58	-	-
	From 10 to ≥ 30 kW	3.33	45.51	-	-
	> 30 kW	2.33	31.86	-	-
Hydro (≤ 10 MW)	≤ 1 MW or ≤ 5 000 MWh/y	0.77	10.47	0.77	10.47
	5 000 - 15 000 MWh/y			0.61	8.34
	≥ 15 000 MWh/y			0.47	6.37
Wind		0.71	9.71	0.72	9.86
Solid biomass	From forestry and agriculture (branches, straw, kernels …)	1.33	18.20	1.15	15.78
	From wood processing industry (bark, saw dust, chips …)	1.05	14.41	0.92	12.59
Geothermal		1.40	19.12	1.40	19.12
Power production on **biogas** from energy crops, waste and residues from agriculture and food processing industry		1.33	18.20	1.15	15.78
Power production on **liquid biofuels**		0.40	5.46	0.40	5.46
Power production on landfill **gas** and waste water treatment gas		0.40	5.46	0.40	5.46
Power production using **other RES** (sea waves, ebb and tide)		0.67	9.10	0.55	7.58

The tariff is guaranteed for a period of twelve years and is adapted to the consumer price index annually. Although the Croatian incentives are comparatively high to other European countries only four wind power projects, five PV plants, two small hydro power plants and one biogas plant are eligible for the feed-in tariff by the year 2010 (Kulišić 2010b). Ognjan et al. (2009) and Kulišić (2010c) denominate the following influences for the dragging RES-deployment:

- Low domestic production, which implies higher prices for imported products (duties)
- Low deployment rates, so-called land-mark projects are missing
- Grid-capacity limits
- Long and complicated permitting procedure
- Insufficient communication between the authorities
- High expenses for the permitting procedure caused by several repetitive documentations for different authorities
- Additionally, the feed-in tariff is only granted for 12 years and currently no clear procedure is outlined for the point in time when the feed-in agreement expires

At the moment a certain point in time, when the administrative procedure will be accelerated, cannot be defined. More information about possible support schemes (feed-in tariffs, the setting of quotas, certificate trade, etc.), the main barriers and the possible optimisation is assessed by the OPTRES project (Ragwitz et al. 2007). With respect to the hereinafter defined off-grid PV reference project it has to be mentioned, that such PV plants are not subject to the above listed legislation. According to Bačan (2010) only a construction permit by the locally responsible office for construction affairs is necessary.

3.3 Potential and future prospect of RES

The Croatian government, in coordination with the European legislation, set the goals of 20 % of the total gross energy consumption by RES in the year 2020 and maintaining the share of 35 % RES-E in the total electricity consumption (incl. large hydro power plants) for a sustainable energy scenario. Therefore specific targets for the different plant types were defined by the Croatian Government. In Table 5 the different electricity production methods with the correlated potential, the projected deployment rate and the current installed capacity are summarised. Scattered values, like the PV potentials, are not defined by the legislative (Stanić 2010 and Kulišić 2010a to 2010c).

Table 5: Potentials and deployment rates for RES technologies in Croatia
Source: Author’s personal research results (2011) based on Stanić (2010) and Kulišić (2010a to 2010c)

<table>
<tr><th colspan="7">Potentials and deployment rates for RES technologies</th></tr>
<tr><th colspan="2" rowspan="2">RES technology</th><th colspan="2">Technical potential</th><th colspan="2">Governmental goal</th><th rowspan="2">Installed capacity in 2008 (MW)</th></tr>
<tr><th>Produced energy p.a. (TWh)</th><th>Installed capacity (MW)</th><th>By 2020 (MW)</th><th>By 2030 (MW)</th></tr>
<tr><td colspan="2">PV</td><td>9.20</td><td>tbd</td><td>tbd</td><td>tbd</td><td>0.08</td></tr>
<tr><td rowspan="2">Wind</td><td>On-shore</td><td>10.00</td><td>4,540</td><td rowspan="2">1,200</td><td rowspan="2">2,000</td><td>17.15</td></tr>
<tr><td>Off-shore</td><td>12.00</td><td>tbd</td><td>0.00</td></tr>
<tr><td colspan="2">Small hydro power</td><td>0.57</td><td>177</td><td>100</td><td>140</td><td>32.76</td></tr>
<tr><td rowspan="2">Biomass</td><td>Biomass, Biogas</td><td>4.70</td><td>2,648</td><td>140</td><td>420</td><td>4.63</td></tr>
<tr><td>Waste</td><td colspan="2">tbd</td><td>40</td><td>60</td><td>0.00</td></tr>
<tr><td colspan="2">Geothermal</td><td>tbd</td><td>48.80</td><td>20</td><td>30</td><td>0.00</td></tr>
</table>

According to Table 5, the largest technical potential in Croatia has wind power, which is also expressed in the planned capacity amounts, although no differentiation between on- and off-shore wind power was done. For reaching the goals in the year 2020 the TSO grid-restriction of 350 MW has to be changed (Stanić 2010). Kulišić (2010c) denotes additional measures, like the improved assessment and centralisation of wind data (Croatian wind atlas), the facilitation of the permitting procedure and serious investments in the grid-capacity, as a prerequisite for the realisation of the targeted objectives.

On the second place of the possible technical potential ranges PV. The Croatian government does not define goals for this technique, justified with the indication of the high costs at the moment (Kulišić 2010c). Until the year 2008 only 80 kW_p grid-connected PV capacity was installed. Bačan (2010) remarks that statistics about off-grid PV plants are not recorded systematically.

Currently small-scale hydro power is the most prevalent RES-E technology in Croatia. Despite that fact, potential is still available and therewith the goals for the future development were set. Besides the technological and economical feasibility environmental protection aspects have to be considered (Kulišić 2010c). Prospects about tidal energy were not mentioned explicitly. Stanić (2010) comments, that existing large-scale hydro power plants will be modernised to generate 300 MW additionally by the year 2020.

Biomass provides large capabilities and hence the Croatian government sets high targets for the future deployment. Kulišić (2010c) points out that the biogas and waste potentials and their degree of utilisation have to be evaluated more exactly. For example, the municipal waste of the millions of tourists provides additional sources. The forest potential is well investigated, but besides the electricity supply also shares for the production of heat and energy carriers (pellets, briquettes) have to be considered. At present two plants, one gas turbine working with landfill gas and one gas engine operated with gas from a sewage plant, both located in Zagreb, are in operation (Kulišić 2010b).

Finally, geothermal electricity production is assumed to contribute to the Croatian electricity production in future. The World Energy Council (2007) states that *„considerable Croatian geothermal resource is located in the south eastern and* *north eastern areas of the country and although usage is increasing, it is still at a very low level. There are 28 reservoirs in the country, with a total potential of about 1,000 MW_t.*" The area of the Panonian basin provides a high temperature gradient of 0.05 °C/m. Only a small proportion of the thermal potential (48.80 MW_e) is planned to be used for the electricity production as water temperatures of more than 100 °C are necessary for an economically reasonable deployment. At the moment geothermal energy is utilized for room heating and the heating of spas (Kulišić 2010a).

In summary, the Croatian government set ambitious targets for the deployment of RES-E technologies all over the country. Despite the technical and economical challenges, it is necessary to diminish legislative and administrative barriers to guarantee sustainable and balanced development potentialities for all technologies.

4 Reference location Kornati archipelago

4.1 Croatian islands

1,185 islands are situated along the 1,777 km long coast from Istria to Dubrovnik. Currently only 47 islands are inhabited because most of the Croatian islands are small islands, rock formation and reefs. According to the Croatian Bureau of Statistics (DZS), nearly 3 % (122,418 persons) of the Croatian Population (4.44 m. people) live on these islands. More particular, the main-island of the Kornati archipelago, Kornat, is listed with 7 permanent inhabitants (DZS 2010). From this figure it becomes clear, that the majority of the residents own houses, which are just inhabited infrequently, mainly during the summer season. The income is generated by olive growing, sheep breeding, fishing, and by touristic activities (restaurants or holiday let). 620 land plots and 51 houses are registered at present (Nacionalni Park Kornati n.d. a and n.d. b).

The Kornati archipelago covers an area of 220 km² and encompasses 89 islands (50 km²). The biggest island Kornat (32 km²) accounts for more than the half of the land size (Nacionalni Park Kornati n.d. c). Together with the bay of Telašćica the Kornati national park is added to the UNESCO's world natural heritage tentative list (Nacionalni Park Kornati n.d. d). This calls for sustainable resource utilisation and environmental protection to preserve the existing unique flora and fauna. Therefore, the request for renewable energies is gaining in importance.

4.2 Characteristics of the Kornati archipelago

The Kornati archipelago is characterised by karst formations with steeps and clips. Significant vegetation is not available as the existing forests were cut down or burned during the Roman times. At present the larger islands are mainly vegetated with pasture vegetation and some cultivation areas, where olive trees are planted. Most of the settlings are built near the olive groves on the wind-sheltered side of the islands. Despite the ordinary pasture vegetation, 700 to 800 plant species are endemic on the Kornati islands, including endangered ones like Euphorbia dendroides, a sort of orchids (Nacionalni Park Kornati n.d. e and n.d. f). Due to the sparse vegetation energy production by biomass combustion or the production of biogas for CHP on the islands can be excluded.

The available rainfall is stored in cisterns for drinking water production. Large natural storage basins or rivers are not available because of the steep land formation, the porous stone structure and the low height of the islands (max. 237 m on Kornat). Hence no hydro power energy supply is possible on the Kornati islands (Nacionalni Park Kornati n.d. b). Also Tidal energy is no possibility as the tide difference in the Adriatic Sea amounts to only 25 cm in the South, up to a maximum of 80 cm in the Northern area (Kroatische Zentrale für Tourismus 2007).

The electricity supply by the use of geothermal energy will not be successful as the temperature gradient reaches only 0.02 °C/m in the coastal areas in contradistinction to the Panonian basin with a higher than average value (0.05 °C/m) (Kulišić 2010a).

The most promising renewable energy technology besides photovoltaic is wind energy. According to a map of the Meteorological and Hydrological Service DHMZ (n.d. a), the mean average wind speeds in the years 1992 to 2001, measured on 10 metres height, reached from 3.50 to 5.40 m/s on the island Kornat. A detailed analysis would bring up suitable locations with even higher wind velocities. Unfortunately, the Croatian legislation prohibits the wind energy use on islands and within a corridor of one kilometre away from the coastal line (Kulišić 2010b). After an amendment of the relevant laws, an energy supply with wind power would be possible in the future. Considering these aspects only photovoltaic energy supply remains suitable for the houses on the Kornati archipelago. This modulatable technology can be fitted to the given conditions to supply remote locations decentralized with energy. In Figure 1 the solar irradiation in Croatia is presented.

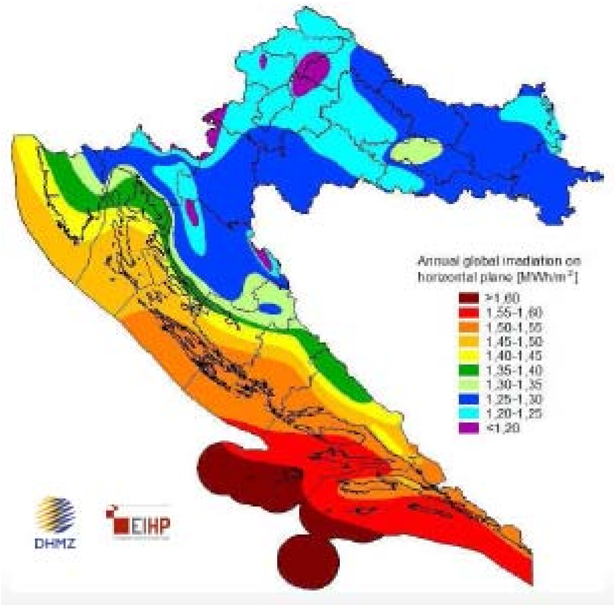

Figure 1: Annual global irradiation on horizontal plane (MWh/m²) in Croatia
Source: DHMZ (n.d. b)

The area of the Kornati region (dark orange) receives an annual irradiation on the plane surface of 1,500 to 1,550 kWh. Besides the irradiation, further aspects like inclination angle, ground reflection and temperature have to be considered, detailed data and analyses for the location Kornat are performed in Chapter 4. „*The mean air temperature in the coastal regions ranges from 12 °C to 17 °C*", in the warmest months the average temperature reaches more than 22 °C (DZS 2010). The wind loads, especially in the wind-exposed coastal areas, have to be considered within the static calculations. The snow load in this area is negligible, meanwhile in the mainland of Croatia this aspect has influence on statics (DZS 2010). Site dependent influences like shadowing effects have to be regarded individually to minimise energy losses and avoid hot spot effects.

4.3 Definition of the reference house

Referring to site visits (compare Annex A) on the islands of the Kornati archipelago a reference house including a restaurant in the bay of Vrulje (43° 48‘ N, 15° 18‘ E) is designed. A roof-mounted small-scale PV plant without tracking system is planned, as the arising costs for the additive tracker investment, operation and maintenance cost stand in no relation with the energy consumption and the initial investments. A reference diesel generator serves as a comparison value.

Most of the houses in the Kornati area are inhabited only semi-annual, from May to October. The utilization ranges from residential houses and tourist apartments, with a low energy demand, up to restaurants, with a larger load profile. The load structure of these houses is in general very simple because

- Diesel and gas have to be delivered by boat to the islands, which is very cost intensive (compare Chapter 5.)
- Inappropriate devices are avoided
- The inhabitants are outside of the house during the day (fishing, cultivation works in the olive groves, etc.)
- No other renewable energy sources are possible (compare Chapter 3.2.).

The most limiting factor concerning the used equipment is the availability of water on the islands. For each house or small merger of neighbouring houses the rainfall is collected in concrete cisterns with limited capacity. The inhabitants abstain from having dish washers and washing machines and instead wash the dishes by hand and bring the dirty laundry to the mainland (compare site visit in Annex A).

Currently, the single houses produce the electricity with small-scale diesel generators (3 to 5 kW) when the energy is needed. Even in settlements or small villages each house has an own generator. During the summer the aggregates run 8 to 10 hours a day. In the winter season the operation hours amount to approx. 2 to 3 hours a day, mainly in the evening when light is necessary. Some plants are equipped with single photovoltaic modules and small battery storages (approx. 100 Ah) to overcome short periods without the engine and supply the 12 V-consumers with energy.

The reference house is designed as a small restaurant with living space, where the owner and his wife live all year long. The rest of the family works and lives on the mainland near Murter and comes for the weekend or holidays. Demand fluctuations during the week are not considered as the consumption is limited per se. In the summer season, starting in the middle of May and lasting until middle of October, 20 guests are hosted, especially for dinner. Cooling devices and cooking facilities are the most crucial equipment for restaurants. At the moment, most of the houses have refrigerators and freezers with gas absorption cooling. The stoves and ovens are also operated by gas. Additionally, all restaurants and many private houses have a traditional grill fired with charcoal (compare Annex A).

To give a comprehensive overview, electrical cooling devices are assumed in this work. Because of the widespread distribution of the gas stoves no change to electrical devices is considered. The warm water preparation will be done with a thermosyphon system, which takes advantage of gravity differences and works without circulation pumps. More information about these systems is documented in Weiss (2010). Additionally, no air condition and no electrical heating devices are available. The heating in winter is conducted with a common wood log stove. In Table 6 the assumed devices in the reference house are listed. Further information like the product specifications are attached in Annex B.

Table 6: Electrical devices in the reference house
Source: Author’s personal research results (2011)

Electrical devices				
Device	Nominal power (W)	Amount	Sum nominal power (W)	Voltage (V)
Freezer	30.50	1	30.50	230
Refrigerator with freezer	37.80	1	37.80	230
TV	40.00	1	40.00	230
Radio	20.00	1	20.00	230
Water pump	60.00	1	60.00	12
Light bulbs	11.00	15	165.00	12
Light bulbs	15.00	5	75.00	12
Energy consumption			428.30	

The devices are market-based and run on 12-V or 230-V voltage level. The visited houses (compare Annex A) are equipped with a suitable cabling for 12-V and 230-V appliances. The 12-V consumers are directly connected to battery via the charge control, the 230-V appliances are supplied by the battery via the charge controller and an inverter. Figure 2 shows the circuit diagram of such a system.

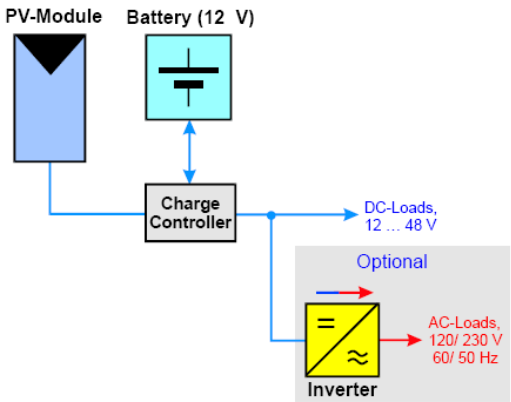

Figure 2: Solar home system with option of AC-generation
Source: Wollny (2005)

During the winter months only the refrigerator with integrated freezer is in operation, storing the food for the inhabitants only. In summer time the freezer is additionally switched on. The other appliances are utilized all year long to a different extent. Table 7 shows two representative months, January and July, for the energy consumption during the winter and summer time. The evaluation for the complete year is attached in Annex B.

Table 7: Energy consumption in representative months
Source: Author's personal research results (2011)

Energy consumption		January				July			
Device	Sum nominal power (W)	h/ d	kWh/ d	d/ mon	kWh/ mon	h/ d	kWh/ d	d/ mon	kWh/ mon
Freezer	30.50	0	0.00	0	0.000	24	0.73	31	22.63
Refrigerator with freezer	37.80	24	0.91	31	28.21	24	0.91	31	28.21
TV	40.00	1	0.04	31	1.24	4	0.16	31	4.96
Radio	20.00	3	0.06	31	1.86	3	0.06	31	1.86
Water pump	60.00	1	0.06	31	1.86	4	0.24	31	7.44
Light bulbs	165.00	2	0.33	31	10.23	2	0.33	31	10.23
Light bulbs	75.00	3	0.23	31	7.13	1	0.08	31	2.48
Energy consumption	428.30		1.63		50.53		2.51		77.81

Table 7 depicts also the great influence of the cooling devices on the energy consumption (max. 1.64 kWh additional consumption caused by both devices per day). The application of the freezer and the further use of TV and water pump increase the energy demand during summer. As an effect of the longer daylight period the energy demand for lightning decreases. At the maximum a load of 429 W is switched on simultaneously. The daily energy consumption ranges from min. 1.63 kWh per day in winter to max. 2.51 kWh per day in summer. The annual consumption amounts to 714 kWh.

4.4 Sun radiation

After determination of the required energy amount, the sun radiation for the reference location is investigated, which is the basis for the energy yield of the PV modules (Wagner 2006). Different references provide sun radiation data for the location in Vrulje or the next bigger cities Šibenik (43° 70’ N, 15° 90’ E) and Zadar/Zemunik (44° 10’ N, 15° 40’ E), both are approx. 40 km linear distance away from the island Kornat. As a reference meteorological station Šibenik is chosen because Vrulje (43° 48‘ N, 15° 18‘ E) is located nearly on the same latitude as Šibenik. Furthermore, the measuring station Zadar/Zemunik is excluded from the investigation because it is situated some kilometres away from the coast in the lands interior and hence cannot be compared with a sea side location like Šibenik.

Data from the NASA used by Retscreen (2010) and of the Solar Radiation Handbook of Croatia (Matič 2007) for the location Šibenik is available. With the data of the European Database of Daylight and Solar Radiation Satel Light (2011) and the program Meteonorm (2008) an exact analyses for the location Vrulje on the basis of the latitude and the longitude is possible. Table 8 compares the daily horizontal sun radiation data (kWh/m²) in each month and the monthly radiation in total by Satel Light and Meteonorm.

Table 8: Comparison of sun radiation part 1
Source: Meteonorm (2008) and Satel Light (2011)

Sun radiation (kWh/m²)		01	02	03	04	05	06	07	08	09	10	11	12	**Sum**
Meteonorm	Daily mean values	1.65	2.50	3.87	5.07	6.32	6.87	6.90	6.00	4.70	3.39	1.93	1.55	
	Monthly values	51	70	120	152	196	206	214	186	141	105	58	48	**1,547**
Satel Light	Daily mean values	1.66	2.63	3.92	4.77	6.53	7.32	7.09	6.31	4.57	2.83	1.63	1.35	
	Monthly values	51	74	122	143	202	220	220	196	137	88	49	42	**1,544**

From the depiction in Table 8 it becomes obvious that the annual amount of solar radiation is nearly equally calculated by both systems. However, high variations of the daily and therewith the monthly values from April to August calculated by Satel Light compared to Meteonorm are significant. Therefore, the Satel Light radiation values from October to December are lower than those stated by Meteonorm. For approaching the correct values of the location Vrulje, the above shown data sets are compared with the sun radiation data of Šibenik calculated in the Solar Radiation Handbook of Croatia.

This reference uses mathematical models proposed by the European Solar Radiation Atlas and combines it with measurement data of Croatian meteorological stations to allocate values for 43 locations all over the country (Matič 2007).

Table 9: Comparison of sun radiation part 2
Source: Meteonorm (2008), Satel Light (2011) and Matič (2007)

Comparison of sun radiation			01	02	03	04	05	06	07	08	09	10	11	12	Sum
Solar Handbook	Daily mean values	kWh/m²	1.62	2.61	3.92	5.21	6.22	6.90	6.90	5.92	4.68	3.33	1.89	1.40	
	Monthly values	kWh/m²	50	73	122	156	193	207	214	184	140	103	57	43	1,542
Meteo-norm	Daily mean values	kWh/m²	1.65	2.50	3.87	5.07	6.32	6.87	6.90	6.00	4.70	3.39	1.93	1.55	
	+/- Solar Handbook	%	1.85	-4.21	-1.28	-2.69	1.61	-0.43	0.00	1.35	0.43	1.80	2.12	10.71	
	Monthly values	kWh/m²	51	70	120	152	196	206	214	186	141	105	58	48	1,547
Satel Light	Daily mean values	kWh/m²	1.66	2.63	3.92	4.77	6.53	7.32	7.09	6.31	4.57	2.83	1.63	1.35	
	+/- Solar Handbook	%	2.47	0.77	0.00	-8.45	4.98	6.09	2.75	6.59	-2.35	-15,02	-13.76	-3.57	
	Monthly values	kWh/m²	51	74	122	143	202	220	220	196	137	88	49	42	1,544

Table 9 reveals the deviation of the Meteonorm (-4.21 to +10.71 %) and the Satel Light (-15.02 to +6.59 %) data from the values of the Solar Handbook even though the annual values are nearly equal. As a decision aid for one data set Figure 3 was computed.

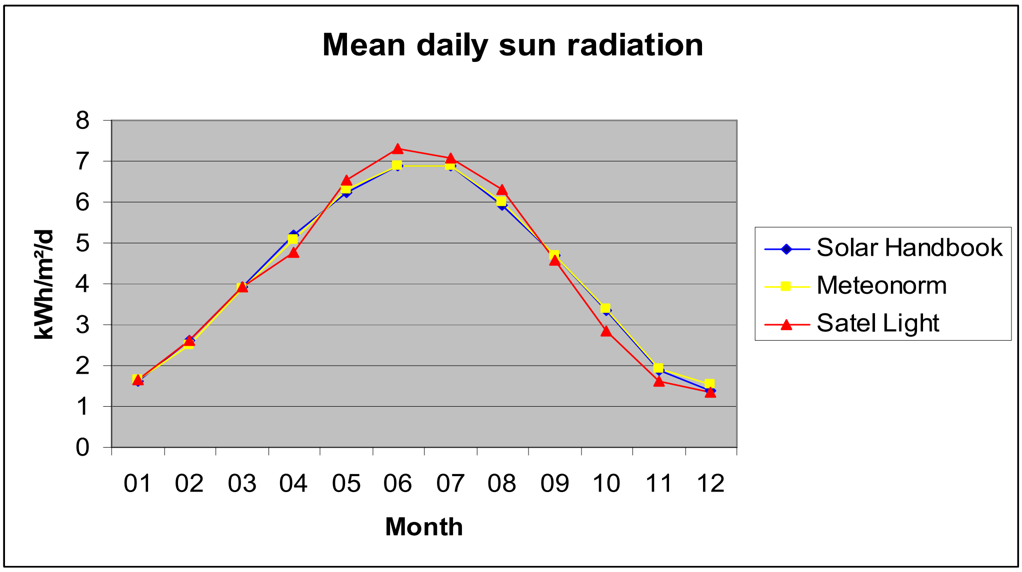

Figure 3: Comparison of mean daily sun radiation
Source: Meteonorm (2008), Satel Light (2011) and Matič (2007)

Figure 3 displays that the Meteonorm data for Vrulje and the values of the Solar Radiation Handbook for Šibenik correspond to a great extent. Hence the data gained by the Meteonorm program is taken as a basis for further calculations. Additional information about the locations Zadar/Zemunik, Šibenik and the investigated sun radiation data can be found in Annex C.

4.5 PV plant configuration

After determination of the sun radiation on a plain surface it is necessary to evaluate the influences of the inclination and the loss coefficients. As explained in Chapter 2.1., the sun radiation, which hits the Earth, consists of direct radiation and scattered light with no fixed orientation. The azimuth and the height of the sun change constantly during a day and over the year. To gain an optimum output of the PV plant it is necessary to find the best possible orientation and inclination (Haselhuhn et al. 2005). Matič (2007) states the optimum orientation of a Croatian PV plant with $\alpha = 0°$ or 180° southwards according to the cardinal points. In the following context only the definition $\alpha = 0°$ will be used. A variation to southwest ($\alpha = 45°$) or southeast ($\alpha = -45°$) will reduce the produced energy yield only by 10 % (Haselhuhn et al. 2005).

To reach an optimum PV yield an inclination with respect to the plant's use has to be chosen. During the summer half-year approx. 75 % of the annual solar radiation is rayed on the Earth. For example, if the plant is installed on a weekend cottage, which is only inhabited during summer, a flatter inclination angle will be advisable to participate from the sun's height at this time of the year. Consistently, a plant in perennial operation needs a steeper angle to optimize the energy output also in the winter half-year, when the sun's height is much lower (Haselhuhn et al. 2005).

For a PV plant in perennial operation Weiss (2010) advises an inclination angle equal to the plant's degree of latitude. Haselhuhn et al. (2005) state, that an inclination angle of 10° to 50° reduces the energy yield by max. 10 %. For the evaluation of the above mentioned statement about the optimum inclination angle, the annual available solar radiation on different tilted surfaces is investigated. Therefore, the inclination angles in steps of 15° (15°, 30°, 45°, 60°) are entered in the program Meteonorm (2008) to compute the corresponding solar radiation values (compare Annex C). For this evaluation also the radiation of the ground reflection of the surrounding area has to be considered. The diffuse radiation is enhanced, when sun light is reflected by a bright ground (e.g. concrete) or water surfaces. A so-called albedo value of 0.51 (Brösicke 1995) is taken into account for the calculation. In Table 10 the resulting monthly data is summed up and compared with the radiation on the horizontal surface to obtain a conversion factor for further calculations.

Table 10: Radiation at different inclination angles
Source: Meteonorm (2008) and author's personal research results (2011)

Radiation (kWh/m²) at different inclination angles													
Inclination	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez	Sum
0°	51	70	120	152	196	206	214	186	141	105	58	48	1,547
15°	72	90	142	166	203	210	221	199	163	131	78	70	1,745
Factor	1.41	1.29	1.18	1.09	1.04	1.02	1.03	1.07	1.16	1.25	1.34	1.45	
30°	89	106	158	173	203	206	218	204	177	152	94	88	1,868
Factor	1.75	1.51	1.32	1.14	1.04	1.00	1.02	1.10	1.26	1.45	1.62	1.83	
45°	101	117	166	173	194	193	206	200	183	165	106	102	1,906
Factor	1.98	1.67	1.38	1.14	0.99	0.94	0.96	1.08	1.30	1.57	1.83	2.13	
60°	108	121	166	165	177	172	186	187	179	169	112	110	1,852
Factor	2.12	1.73	1.38	1.09	0.90	0.83	0.87	1.01	1.27	1.61	1.93	2.29	

Table 10 depicts the advantage of a steeper angle during winter time, e.g. in January when the 45° tilted surface receives nearly double radiation than the plain surface. Meanwhile in summer, the surfaces with flat inclination benefit from the sun's high altitude. Correspondent to Table 10, the PV plant is planned with 45° inclination, which nearly coincides with Vrulje's degree of latitude (43° 48' N).

The location and the mounting of the PV plant influence the energy yield furthermore. Heat, occurring by rising outside temperatures and by the lack of ventilation due to the mounting, decreases the module efficiency. Häberlin (2010) offers three variants (low, medium, high influence) of factors depending on the mounting (ground-mounted, roof-mounted with ventilation, building-integrated), the implemented modules (crystalline, thin-film) and the region from Northern to Southern Europe (compare Annex C). For further calculations values of roof-mounted systems in Marseille, depicted in Table 11, are taken into account, as the city (43° 30' N) is situated nearly on the same latitude as Vrulje. A comparison of the climate regions with the program Meteonorm (2008) comes to the same results, as Split, in near vicinity to Vrulje, is classified similarly to Marseille in the climate group IV.

Table 11: Heat coefficient
Source: Häberlin (2010)

Heat coefficient												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Factor	0.98	0.98	0.95	0.93	0.91	0.89	0.87	0.88	0.91	0.93	0.97	0.98

Another yield reduction factor is the limited efficiency of the solar module itself to convert sunlight into electrical energy (compare Chapter 2.1.).

With respect to a regional value creation Croatian PV module producers are considered. The three companies, Solartehnika (modules from 210 to 240 Wp), Solaris Sunčeva Energija (22 to 240 Wp) and Solvis (120 to 280 Wp), manufacture crystalline modules domestically (ENF 2011a, Solvis n.d.). Only one manufacturer, Solar Cells, formally Koncar Solar Cells, produces thin-film modules based on amorphous silicon in a range of 2 to 14 Wp (ENF 2011b).

The poly-crystalline module SV36-125 of Solvis, with 1.03 m² surface and a maximum power of 125 Wp is chosen, because this module works at the 12 V-battery operating voltage (12.50 to 13.50 V). More information about the module is attached in Annex D (Solvis n.d.). None of the Croatian module producers states the module efficiency at STC on its homepage. On request only Solvis offered the values; the SV36-125 module has an efficiency degree of 12.20 % (Kubat 2011).

The energy output of the PV modules is additionally influenced by shading. This can be caused by buildings or building parts, trees or other obstacles in the surrounding (Haselhuhn et al. 2005). For the reference location no shading is assumed as the native trees (mainly olive trees) do not grow taller than eight metres and therewith do not top the house roof (Baumkunde.de n.d.).

Besides the shading, smog, air pollution and dirt can lower the module yield (Nemac 2010). Neither of the first two factors is further investigated as no industry or cars are present on the Kornati islands. Reductions by dirt are not considered because soiling is avoided by the inclination of the modules as the rain washes dust particles automatically away (Fechner 2010). With a mean annual temperature of 12 to 17 °C along the Croatian coast snow falls occur just irregularly and then the snow does not deposit on the ground for a long time (DZS 2010). Hence a yield loss caused by snow fall is not considered. The loss factors pointed out by Haselhuhn et al. (2005) (compare Chapter 2.1.) are considered:

- 6 % cabling losses (3 % losses at the cables from the PV plant to the charger controller and further on to the battery and 3 % losses at the cables from the battery back to charge controller and further on to the consumers)
- 10 % losses by module degradation over the plant operation time
- 10 % mismatching losses as no MPP-tracker will be implemented

All the above mentioned factors are consolidated and multiplied with each other to receive the possible daily output (kWh/m²). The plant availability is assumed with 100 %. In Table 12 the months January and July are instanced.

Table 12: Calculation of the daily energy yield in representative months
Source: Author's personal research results (2011)

Daily energy yield in representative months				January		July	
Sun radiation	F1		kWh/(m² · d)		1.65		6.90
Inclination	F2	45°	Factor	1.98		0.96	
Heat coefficiant	F3	roof-mounted	Factor	0.98		0.87	
Module efficiency	F4	12.20 %	Factor	0.12		0.12	
Cable losses	L1	6.00%	Factor	0.94		0.94	
Conversion losses	L2	10.00%	Factor	0.90		0.90	
Mismatch losses	L3	10.00%	Factor	0.90		0.90	
Real energy yield	F1xF2xF3xF4xL1xL2xL3		kWh/(m² · d)		0.30		0.54

In Table 12 the high influence of inclination and heat coefficient on the daily energy yield (kWh/(m² · d) becomes obvious. Based on the evaluation of the possible energy output the PV plant is dimensioned. The plant size is computed by dividing the daily energy demand by the product of the given module surface and the daily energy yield per square metre. E.g. below the calculation for July:

$$\frac{2.51\,\text{kWh/d}}{1.03\,\text{m}^2 \cdot 0.54\,\text{kWh/(m}^2 \cdot \text{a)}} = 4.51\ \text{modules}$$

This calculation is computed for all months and the highest result, 5.28 modules in December and January, is rounded up, to receive the final dimension. The PV plant will consist of 6 parallel connected 125 Wp-modules with an overall nominal power of 750 W. The module surface area amounts to 6.18 m² and thus is suitable for a rooftop of a single-family house. With the resulting plant size (amount and size of the modules) and the daily, monthly and annual energy yield, the surplus energy and the available reserves are computed. The daily energy production ranges from 1.85 kWh in winter to a maximum of 3.34 kWh in July. All over the year 1,012.14 kWh can be produced. The surplus reaches min. 0.22 kWh per day (13.50 %) in January and December and max. 1.46 kWh per day (89.57 %) in April. In the main season the surplus energy amounts to approx. 30 % as the energy demand is significantly higher than in April. The entire plant configuration, including the dimensioning and the resulting daily values and percentages, is attached in Annex D.

As suggested by the World Energy Council (2010) and Haselhuhn et al. (2005) the annual performance ratio (PR) and the final yield (FY) are investigated.

$$PR = \left(\frac{E_{REAL}}{E_{IDEAL}} \right) = \left(\frac{\text{Computed energy yield}}{\text{Sun radiation (kWh/m²)} \cdot \text{Plant size (m²)} \cdot \eta\,(\%)} \right)$$

$$= \left(\frac{1{,}012.14\ \text{kWh}}{1{,}547\ \text{kWh/m²} \cdot (1.03\ \text{m²} \cdot 6\ \text{modules}) \cdot 12.20\ \%} \right) = \left(\frac{1{,}012.14\ \text{kWh}}{1{,}166.38\ \text{kWh}} \right)$$

$$PR = 86.78\ \%$$

The PR is the quotient of the real energy yield, which considers all loss factors, and the ideal energy yield, which regards only the module's efficiency as limiting factor. The final PR-result of 86.78 % is higher than the recommended value of 70 to 85 % (Haselhuhn et al. 2005).

$$FY = \left(\frac{E_{REAL}}{P_n\,PV} \right) = \left(\frac{1{,}012.14\ \text{kWh/a}}{0.75\ \text{kWp}} \right)$$

$$FY = 1{,}349.52\ \text{h/a}$$

The annual final yield represents the full load hours per year, resulting by dividing the real energy yield by the nominal power of the PV system. The reference PV plant operates 1,349.52 hours per year.

4.6 Battery storage configuration

To overcome days without sun shine or too low sun radiation and to supply energy during the night, battery storage systems are necessary. Further information about possible storage types is listed in Chapter 2.6. In the following section a suitable storage size for the above defined PV plant is designed. Therefore, conventional lead acid batteries on a 12-V voltage level are installed. Haselhuhn et al. (2005) offer the following formula to calculate the battery capacity (C_n) in Ah:

$$C_n = \frac{2 \cdot W \cdot F}{U_n}$$

The necessary daily energy amount (W) is multiplied by factor of the autonomous days (F).

To enhance the lifetime of the battery the limitation to only 50 % discharge is reasonable. Therefore, the figure 2 is used as a multiplier. The result of the multiplication is divided by the applied battery voltage level (U_n). For the location Vrulje, the factor of the autonomous days in summer (April to September) is set to 2.50 days (F_s) and to 4.00 days in winter (October to March) (F_w). In summer it is much more likely that only short periods without sun will occur than in winter. The calculation states the highest value of 1,140 Ah in October to overcome four autonomous days. In April the lowest battery capacity (679.17 Ah) is necessary. The highest value in October is rounded up to 1,250 Ah, which can be covered by five 250 Ah batteries. The calculation of the battery capacity is attached in Annex D.

4.7 Diesel generator configuration

At the moment most of the houses on the island Kornat have their own diesel generator with a capacity of greater or equal 3 kW to produce energy if necessary. Hence the units are running up to 10 hours a day in the main season, especially in the evening, when the inhabitants are at home and the guests of the restaurant are served. With regard to the load profile it has to be clarified that currently no full-day devices are in operation, because the cooling appliances utilize gas.

Some plants have a small battery storage, approx. 100 Ah, attached to overcome short periods without the diesel generator and supply the 12-V appliances with energy (compare Annex A). More information about generators is listed in Chapter 2.7. Considering the investment costs per kW, the fuel consumption and the power output, a new 4 kW air-cooled, four-stroke single cylinder diesel generator with direct injection and a continuous output of 3 kW is taken into account. The hourly fuel consumption amounts to 1.20 litres. A fuel tank volume of 11 litres enables the daily energy production without refilling (Rotek 2007, Rotek 2010). Additionally, a 110 Ah battery backup with charge controller is considered.

The operation time amounts to 3 hours in the winter season from November to April. In May and October 4.50 hours are assumed. In the main season an operation time of 8 hours per day is defined. The yearly full load hours are depicted in the Table 13.

Table 13: Annual diesel operating hours
Source: Author's personal research results (2011)

Annual operating hours			
Month	**Daily operation hours**	**Days per month**	**Monthly operation hours**
Jan	3.00	31	93.00
Feb	3.00	28	84.00
Mar	3.00	31	93.00
Apr	3.00	30	90.00
May	4.50	31	139.50
Jun	8.00	30	240.00
Jul	8.00	31	248.00
Aug	8.00	31	248.00
Sep	8.00	30	240.00
Oct	4.50	31	139.50
Nov	3.00	30	90.00
Dec	3.00	31	93.00
Sum		365	**1798.00**

The diesel generator operates 1,798 hours a year, for further calculations 1,800 hours are considered. Investigations about the non-recurrent and the operational costs are performed in Chapter 5.

5 Economic evaluation

5.1 Price evaluation PV system

Module prices

The investment costs of the PV system are mainly influenced by the module prices (approx. 70 % of the overall project costs of small-scale projects) (Nemac 2010). With increasing plant size a cost reduction is feasible (economies of scale-effect). Additionally, the decrease in module prices during the last years, caused by an enormous extension of the production capacities (compare Chapter 6.1.), leads to a change in the cost structure. Lippitsch et al. (2009) state a reduction of the module share to 55 to 65 % of the overall costs. Latest price indices (May 2011) by Solarbuzz (2011a) report a module quota of 50 to 60 %. For the price evaluation in Table 14 Croatian internet portals (omnibus.hr 2011), publications of official institutes (Croatian Center of RES 2011) and websites of several retailers (Asel

2011, Elgrad 2010, Ugo 2010) were investigated to list current prices for modules with a nominal power from 120 to 135 Wp. The results were clustered in mono- and poly-crystalline modules. The Solaris systems work with a conjunction of both crystalline structures. Thin-film modules are not further regarded for the reference project because the Solar Cell products provide only low performance ranges (2 to 14 Wp). The prices for the modules are without Croatian VAT of 23 % and converted to Euro with a rate of 7.30 Kn/€. Finally, the module prices are computed to Watt peak-basis to make them comparable.

Table 14: Module prices in Croatia
Source: Author's personal research results (2011) based on Asel (2011), Croatian Center of RES (2011), Elgrad (2010), Omnibus.hr (2011) and Ugo (2010)

Module type	Wp/ module	Producer	Price (Kn)/ module	Price (€)/ module	€/Wp	Date	Source
Mono	130	n.u.	2,942.00	403.01	3.10	2010	Elgrad
Mono	130	Suntech	2,395.01	328.08	2.52	15.02.2011	Omnibus
Mono	120	n.u.	2,236.77	306.41	2.55	2010	Ugo
Mono	120	n.u.	2,137.28	292.78	2.44	15.02.2011	Omnibus
Mono	120	n.u.	1,917.60	262.68	2.19	18.05.2011	Asel
Mono+Poly	125	Solaris	2,973.67	407.35	3.26	15.02.2011	Omnibus
Poly	135	Kyocera	2,610.00	357.53	2.65	15.02.2011	Omnibus
Poly	125	Solvis	2,328.04	318.91	2.55	15.02.2011	Omnibus
Poly	125	Solvis	2,263.09	310.01	2.48	26.03.2011	Cr. Center of RES

Table 14 shows a decrease in prices over time, which coincides with the general market trend, although the Solaris module costs (3.26 €/Wp) are outstandingly high. No correlation between module type and price appears. Principally, mono-crystalline modules are more expensive than poly-crystalline modules due to the higher production costs and the higher silicon quality resulting in higher efficiency rates (Haselhuhn et al. 2005). Calculation data for Solartehnika was not available by the retailers but Omnibus.hr (2011) mentions that the prices of Solartehnika are similar to the prices of Solaris. Thus a detailed comparison between the domestic producers Solaris and Solvis is conducted.

Table 15: Comparison of Croatian module manufacturer's prices
Source: Author's personal research results (2011) based on Croatian Center of RES (2011) and Omnibus.hr (2011)

Nominal power (Wp)	Solvis			Solaris			Price difference (%)
	Poly-crystalline			Mono- and poly-crystalline			
	Source: Cr. Center for RES			Source: Omnibus.hr			
	Price (Kn)/ module	Price (€)/ module	€/Wp	Price (Kn)/ module	Price (€)/ module	€/Wp	
70	1,265.30	173.33	2.48	1,788.48	245.00	3.50	41.13
75	1,355.68	185.71	2.48	1,849.07	253.30	3.38	36.29
80	1,446.06	198.09	2.48	1,945.94	266.57	3.33	34.27
85	1,536.44	210.47	2.48	2,072.30	283.88	3.34	34.68
90	1,626.82	222.85	2.48	2,190.24	300.03	3.33	34.27
95	1,717.20	235.23	2.48	2,274.48	311.57	3.28	32.26
120	2,172.57	297.61	2.48	2,855.74	391.20	3.26	31.45
125	2,263.09	310.01	2.48	2,973.67	407.35	3.26	31.45
130	2,353.62	322.41	2.48	3,090.96	423.42	3.26	31.45
135	2,444.14	334.81	2.48	3,209.54	439.66	3.26	31.45
145	2,625.19	359.62	2.48	3,369.60	461.59	3.18	28.23
215	3,736.82	511.89	2.38	3,959.28	542.37	2.52	5.88
220	3,823.72	523.80	2.38	4,043.52	553.91	2.52	5.88
230	3,997.53	547.61	2.38	4,212.00	576.99	2.51	5.46
235	4,084.43	559.51	2.38	4,296.24	588.53	2.50	5.04
240	4,171.33	571.42	2.38	4,380.48	600.07	2.50	5.04

From Table 15 it becomes obvious that the poly-crystalline modules by Solvis offer the most competitive prices compared to Solaris. Solvis also manufactures mono-crystalline systems, which are not considered in this comparison. Especially, small-scale applications with Solvis poly-crystalline modules up to 145 Wp have a significant price advantage (from 28 % up to 41 % cost savings compared to Solaris). In the range from 215 to 240 Wp the price difference amounts only to approx. 5 %. Thus the mono- and poly-crystalline compound of Solaris would be competitive, if a higher efficiency degree than Solvis could be reached. As Solaris did not provide the exact efficiency values, Solvis modules are taken as a basis for the comparison with the European module prices and further calculations.

Šimić (2011) implies that the prices of the Croatian modules correspond to the European market prices and to the development of the last years. The price development of the last two years (compare Chapter 6.1.) has been characterised by an explosive expansion of the production capacities and partially rapid shifts in the rate of the demand growth caused by changes in countries' feed-in tariff systems. In 2011 the retail price is still declining as a module over-supply exists (Solarbuzz 2011a).

The PVX, the spot market price index for solar modules, shows a price decrease of nearly 40 % for crystalline (decrease from 2.62 to 1.61 €/Wp) and thin-film modules (e.g. CdS/CdTe decrease from 1.78 to 1.09 €/Wp) from May 2009 to April 2011. These wholesale prices indicate the rapid market movements, which will also affect the retail prices (pvXchange 2011). Solarbuzz (2011a), a leading research company, provides monthly a year-long price development overview. The current figures from May 2010 to May 2011 show a price decrease of 19 % for modules with a nominal power of 125 Wp or higher. The current average price of 2.69 €/Wp is calculated by 403 samples of various companies worldwide and includes mono- and poly-crystalline and thin-film modules, respectively. The share of prices below 2.25 €/Wp, mostly thin-film modules, amounts to 34 % of the survey. The price index of 2.69 €/Wp corresponds to the current price of a 125 Wp Solvis module, 2.48 €/Wp, and with the other Croatian module prices listed in Table 15.

PV system components

The further PV system costs are attributed to the inverter(s) (7 to 12 %), the module racks (7 to 15 %), the planning (2 %) and installation (min. 3 %) and the utilized material, like cables and switches (10 %) (Lippitsch et al. 2009, Nemac 2010). These prices vary i.a. by the plant use (grid-connected or off-grid), the project size, the location, the mounting system and the national technical specifications (IEA PVPS 2010). For example, mounting systems on sloping or flat roofs have lower material and installation costs than free-standing ground-mounted rack systems, which need a special foundation (concrete, pile or screw foundation) (Lippitsch et al. 2009, Haselhuhn et al. 2005). For the reference project the cost structure mentioned in Table 16 is assumed.

Table 16: Shares of system components costs
Source: Author’s personal research results (2011)

System components	Share (%)
Modules	70
Inverter	9
Material (cables, switches)	9
Mounting system	7
Planning and installation	5
Sum	100

Investment costs PV system

On basis of the module price (2.48 €/Wp) and the cost distribution in Table 16, a cost allocation for the plant size of 750 Wp is performed. Šimić (2011) mentions that no domestic PV industry is available and all components, apart from the modules, have to be imported. Hence a mark-up of 10 % is added to the calculation prices. Additionally, the transport costs to the island Kornat must be regarded. A transport by boat costs 20.00 € (two ways each 20 nm, the boats run at an average speed of 5 nm per hour with a fuel consumption of 2 litres per hour) at a price for one litre diesel of 1.25 € (June 2011) (Gasoline-Germany 2011). The final cost calculation is depicted in Table 17 below.

Table 17: PV system costs
Source: Author's personal research results (2011)

System components	Share (%)	Cost distribution (€)	Price markup (€)	Final price (€)
Modules	70	1,860.00	0	1,860.00
Inverter	9	223.20	22.32	245.52
Material (cables, switches)	9	223.21	22.33	245.52
Mounting system	7	173.60	17.36	190.96
Planning and installation	5	124.00	12.40	136.40
Transport	0	20.00	0	20.00
Sum	**100**	**2,624.00**	**74.40**	**2,698.40**

The investment costs for the 750 Wp PV system amount to 2,698.40 € or 3.60 €/Wp.

Investment costs Battery system

Lewis (2010) denotes investment costs of 1.50 € per Ah, which implies costs of 1,875.00 € for the reference plant (1,250 Ah). Omnibus.hr (2011) lists the prices in Table 18 for larger lead batteries with liquid and gelled electrolyte at 12-V voltage level.

Table 18: Price comparison of lead batteries
Source: Author's personal research results (2011) based on Omnibus.hr (2011)

Electrolyte	Ah	Price (Kn) /Battery	Price (€) /Battery	Price (€) /Ah	Investment costs for 1,250 Ah (€)
Liquid	250	2,040.26	279.49	1.12	1,400.00
Gelled	230	2,781.00	380.96	1.66	2,075.00

The current market prices, depending on the utilized technology, conform to the statement of Lewis. For the reference project lead batteries with liquid electrolyte are chosen. The lifetime is assumed to be six years. To maintain the battery performance over the years a charge controller is necessary. At the reference project such a device with 40 Ampere is implemented. Solarbuzz (2011b) lists a current price of 3.97 € per Ampere, therewith 158.80 € in total. Omnibus.hr (2011) states costs for such a device with 1,206.00 Kn or 165.21 €, which corresponds with the worldwide prices.

Overall PV investment costs

In Table 19 the component's cost are aggregated to a total investment sum of 4,263.61 €.

Table 19: Overall PV investment costs
Source: Author's personal research results (2011)

Overall PV investment costs	**Price (€)**
Modules	1,860.00
Inverter	245.52
Material (cables, switches)	245.52
Mounting system	190.96
Planning and installation	136.40
Batteries	1,400.00
Charge controller	165.21
Transport	20.00
Sum	**4,263.61**

PV Operation and maintenance (O&M) costs

Over the project lifetime of 20 years additional costs have to be taken into account. The degradation of the PV modules is already considered with an average value of 10 % in the energy yield calculation. Solvis (n.d.) offers a performance warranty of 90 % power output for 12 years and 80 % for 25 years. The damage of the PV plant is covered by insurance. The annual fee amounts to 0.50 % of the PV investment costs (13.49 € p.a.). The PV plant is privately owned therefore no rent has to be paid. The owner will conduct a regular visual inspection of the modules and cabling. Additionally, a plausibility check of the quoted energy yield is recommended (Seltmann 2000). Costs for the assumed time exposure of 30 minutes per week (26 hours per year) are not taken into consideration. Although PV plants work fully automatically problems can occur over the project lifetime, so a factor of 0.25 % of the investment costs for repair and maintenance (6.75 € p.a.) is added annually (Nemac 2010). Besides the annual costs, a replacement of the batteries after every six years is planned. The price is considered to be equal with the initial battery investment costs (1,400.00 €). The overall costs (4,200.00 €) are distributed equally on the 20 years plant lifetime (210.00 € p.a.). In Table 20 all annual costs are summed up to 230.24 €.

Table 20: Annual PV O&M costs
Source: Author's personal research results (2011)

Annual PV-O&M costs	**Price (€)**
Insurance fee	13.49
Repair and maintenance	6.75
Battery reinvestment	210.00
Sum	**230.24**

5.2 Price evaluation diesel generator system

Investment costs diesel generator and battery system

The reference diesel generator by Rotek, described in Chapter 4.7., provides a detailed product description and standards for maintenance. Although the product is from Austrian origin, similar diesel engines, e.g. by Yanmar Marine (n.d.), are delivered to the Croatian market. The investment costs amount to 1,086.00 € (Rotek n.d.), the installation can be done according to the product description by a technically adept person (Rotek 2007). For the transport also 20.00 € corresponding to the PV system transport is assumed. The diesel generator weighs 83 kg and can be transported by boat to the island. The price for the 110 Ah battery amounts to 915.71 Kn or 125.44 € (Omnibus.hr 2011). To prolong the lifetime of the battery a charge controller, equal to the PV system, with a price of 1,206.00 Kn or 165.21 € is considered (Omnibus.hr 2011). The overall investment costs for the diesel generator system in Table 21 sum up to 1,396.65 €.

Table 21: Overall diesel generator investment costs
Source: Author's personal research results (2011)

Overall diesel investment costs	**Price (€)**
Generator	1,086.00
Battery	125.44
Charge controller	165.21
Transport	20.00
Sum	**1,396.65**

Diesel generator O&M costs

The fuel costs and operation and maintenance works amount to a considerable cost proportion over the project lifetime of 20 years. At an annual operation time of 1,800 hours and a fuel consumption of 1.20 litres per hour, 2,160 litres are consumed. Additionally the transport costs have to be considered. As no collective fuel transport is available, the inhabitants travel once a week to the mainland, to shop and to take the diesel with them on the way back. The nearly weekly transport (assumption of 50 times a year) over 20 nm each way is carried out by boats, which run at an average speed of 5 nm per hour and with a fuel consumption of 2 litres per hour. A diesel consumption for the transport of 800 litres is resulting. The price for one litre diesel is set with 1.25 € (June 2011) (Gasoline-Germany 2011). Further price developments of fossil fuels and respective scenarios are stated in Chapter 6.2.

Besides the fuel costs, the operation hours influence the operation and maintenance expenditures. The owner will conduct regular inspections and maintenance works, like the change of oil or air and fuel filters. A detailed plan by the producer Rotek (compare Annex E) sets limits of 100, 300 and 1000 operation hours for routine works, which can be conducted by the owner or by a specialist (Rotek 2007). Caused by the high operation hours tasks, like the change of oil, are suggested 18 times a year. The strict observance of these intervals would lead to enormous O&M costs, although Croatia has low labour costs. Hence in the field the intervals are extended. A reasonable maintenance plan with partly prolonged service intervals and the necessary material and specialist costs is provided in Annex E. The work time of the owner (approx. 46 hours) is not further considered. The costs for the annual operation and maintenance are presented in Annex E and amount to 505 € per year and result from costs for the motor oil, the replacement of filters and the annual check up by a specialist.

The high operation hours deteriorate the diesel generator and after a certain operation time the engine has to be replaced. Elmag (n.d.) points out that the lifetime of a diesel generator depends on the period of application (part-time or 24 hours a day) and the construction type (air or water cooled) and sums up to 3,000 and max. 15,000 operation hours. The replacement of the reference engine is optimistically assumed every six years or 10,800 operation hours. The reinvestment costs (3,258.00 €) are set equally with the initial generator investment costs (1,086.00 €) and are distributed evenly on the 20 years plant lifetime (162.90 € p.a.).

The starter battery (12 V, min. 17 Ah) (Rotek 2007), included in the engine's delivery range, has to be replaced regularly. Due to the every day use a battery exchange every second year (7 times over the project lifetime) is set. The battery costs are assumed to be 50.00 € and distributed on the overall operation time (17.50 € p.a.). The 110 Ah battery storage has to be replaced also regularly. The interval is determined with only 4 years, assuming a higher degradation than within the larger PV battery system. The reinvestment costs for the storage batteries (5 times 125.44 €) are allocated to the plant lifetime (31.36 € p.a.). The O&M are summarised in Table 22 and amount to 4,416.76 €.

Table 22: Annual diesel O&M costs
Source: Author's personal research results (2011)

Annual diesel O&M costs	**Price (€)**
Fuel	2,700.00
Fuel transport	1,000.00
Repair, Maintenance	505.00
Reinvestment generator	162.90
Reinvestment starter battery	17.50
Reinvestment battery	31.36
Sum	**4,416.76**

5.3 Electricity costs

The above listed costs are aggregated to evaluate the long run marginal costs for electricity ($LRMC_{EL}$). Weißensteiner (2009) theorises that „*marginal costs in microeconomics constitute costs occurring while producing an additional (marginal) unit of some product. […] Accordingly, capital costs (costs related to the initial investment into the production facility/equipment) are not included here. When viewing the energy system as a whole the costs of electricity production for one (existing) specific plant within one planning period are regarded as (short run) marginal while generation costs of an additional plant are regarded as long run marginal cost.*" The formula for the electricity cost calculation without consideration of CO_2-emission allowances is offered by Weißensteiner (2009) as follows:

$$LRMC_{EL} = c_{FIX} + c_{VAR}$$

$$LRMC_{EL} = \left(\frac{\alpha \cdot c_{INV}}{T} \right) + \left(\frac{c_{FUEL}}{\eta_{EL}} + c_{VAR\ O\ \&\ M} \right)$$

$LRMC_{EL}$	Long run marginal cost of electricity generation [€/MWh]
α	Capital recovery factor [1]
c_{INV}	Investment costs [€/MW]
T	Full load hours [h/y]
c_{FUEL}	Fuel costs [€/MWh prim]
η_{EL}	Efficiency factor (electrical) [1]
$c_{VAR\,O\,\&\,M}$	Variable costs for operation and maintenance [€/MWh]

The LRMC consist of the fixed investment costs and the variable costs for fuel, if applicable, and costs for operation and maintenance. The capital recovery factor (CRF) α influences the LRMC additionally. The α parameters interest rate and time horizon for the investment are dependent on the investor’s preferences. The below mentioned formula describes the CRF calculation (Weißensteiner 2009):

$$\alpha = \frac{z \cdot (1+z)^{LT}}{(1+z)^{LT} - 1}$$

z	Interest rate [1]
LT	Lifetime / depreciation time [y]

The interest rate is set with 7.70 % according to the Croatian Banks’ weighted average interest rates for Kuna credits indexed to a foreign currency (e.g. Euro) in February 2011 (DZS 2011). The plant lifetime amounts to 20 years. The CRF α for both investments is calculated as follows.

$$\alpha = \frac{7.70\,\% \cdot (1 + 7.70\,\%)^{20}}{(1+7.70\,\%)^{20} - 1} \approx 0.10$$

Die CRF totals up to approx. 0.10, within the subsequent calculations the exact value with several decimal places is considered.

Photovoltaic LRMC

$$LRMC_{EL\,PV} = \left(\frac{(c_{INV} + c_{BATT}) \cdot \alpha}{Q_{SOL} \cdot \eta_{EL}} \right) + (c_{VAR\,O\,\&\,M})$$

The formula provided by Weißensteiner (2009) is adapted to the conditions of the PV system as no fuel costs have to be considered. The investment costs for the PV plant and the battery system are multiplied by the CRF α. This result is divided by the available sun radiation (1,547 kWh/(m² · a) on the module surface (6.18 m²) and the overall PV system efficiency. The efficiency values vary over the months (compare Chapter 4.5.), hence an average efficiency degree of 10.59 % is determined by dividing the annual energy output (163.77 kWh/m²) by the available sun radiation (1,547 kWh/m²). The annual variable O&M costs were already analysed in Chapter 5.1. This figure has to be divided by the annually produced electricity amount to receive the costs per kWh. The final LRMC calculation for the fixed and the variable costs is computed as follows:

$$LRMC_{EL\,PV} = \left(\frac{(2{,}698.40\ € + 1{,}565.21€) \cdot 0.10}{1{,}547 kWh/(m^2 \cdot a) \cdot 6.18\ m^2 \cdot 10.59\ \%} \right) + \left(\frac{13.49\ € + 6.75\ € + 210.00\ €}{1{,}547 kWh/(m^2 \cdot a) \cdot 6.18\ m^2 \cdot 10.59\ \%} \right)$$

$LRMC_{EL\,PV}$ = 0.42 + 0.23 = 0.65 €/kWh

The electricity production costs, with the combined PV and battery system, amount to 0.65 €/kWh. If only the PV related costs are investigated, the LRMC value will drop to 0.29 €/kWh. Considering the higher Croatian investment costs, this value correlates with the current electricity price of 0.30 USD/kWh or 0.21 €/kWh by residential PV systems in sunny climate published by Solarbuzz in May 2011 (2011c). The currency exchange rate is set with 1.44 USD/€ (Finanzen.net 2011). In Figure 4 the cost distribution of the computed LRMC is depicted.

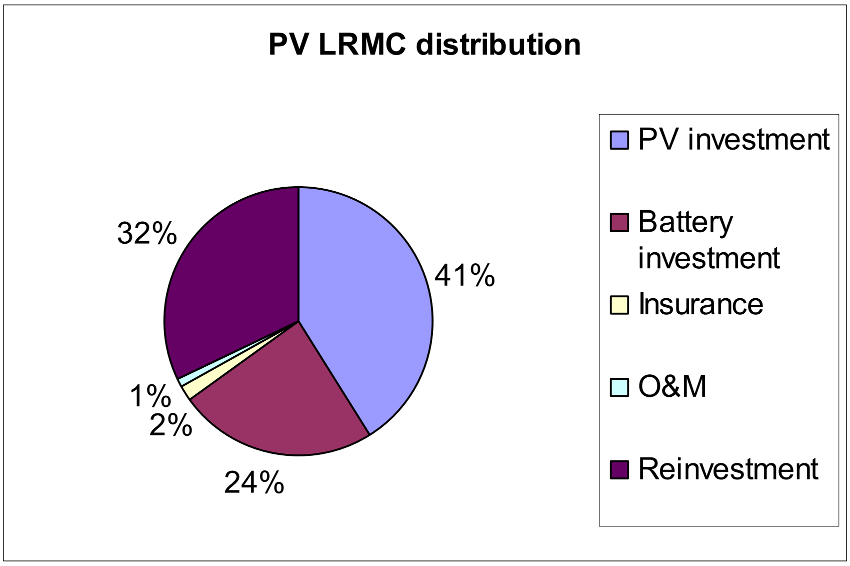

Figure 4: PV LRMC distribution
Source: Author’s personal research results (2011)

Figure 4 illustrates the high influence of the investment and reinvestment expenditures. The real O&M expenses amount only to 3 % of the electricity production costs.

Diesel LRMC

The diesel related data is inserted in the formula given by Weißensteiner (2009):

$$LRMC_{EL\,D} = \left(\frac{\alpha \cdot c_{INV}}{T}\right) + \left(\frac{c_{FUEL}}{\eta_{EL}} + c_{VAR\,O\,\&\,M}\right)$$

$$LRMC_{EL\,D} = \left(\frac{0.10 \cdot (1{,}106.00\,€ + 290.65\,€)}{1{,}800\,h}\right) + \left(\frac{\frac{1{,}800\,h \cdot 1.20\,l \cdot 1.25\,€ + 800\,l \cdot 1.25\,€}{1{,}800\,h \cdot 3\,kW}}{0.80} + \frac{716.76\,€}{1{,}800\,h \cdot 3\,kW}\right)$$

$LRMC_{EL\,D}$ = 0.08 + 0.99 = 1.07 €/kWh

The diesel energy production costs sum up to 1.07 €/kWh. The percentage shares of the LRMC are displayed in Figure 5.

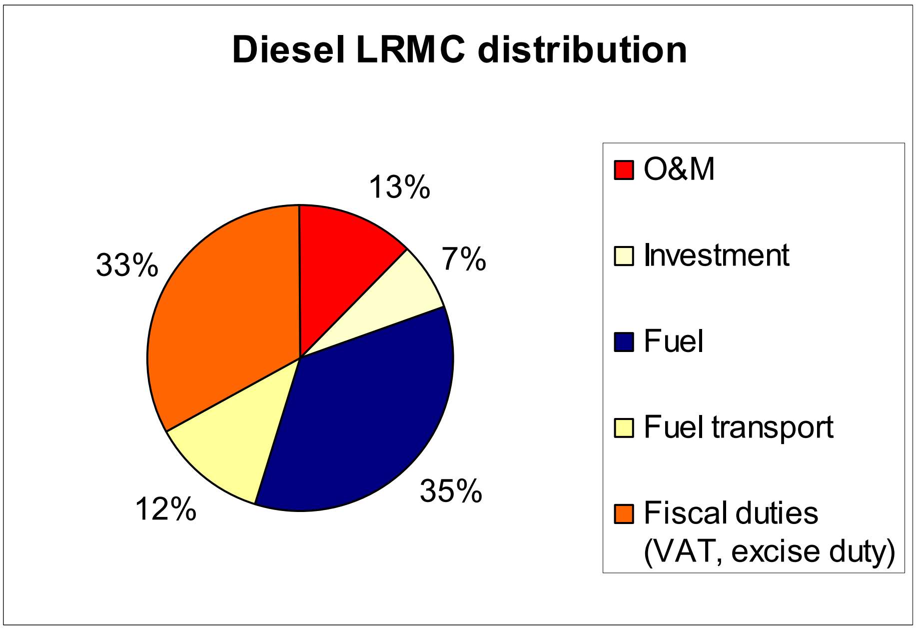

Figure 5: Diesel LRMC distribution
Source: Author's personal research results (2011)

Contrary to the PV costs with low variable costs, has the diesel generator high fuel costs, consisting of the diesel and the fuel transportation costs, which account for 81 % (0.86 €/kWh) of the LRMC. In these costs are expenses for the VAT and the excise duty with a height of 40.80 % contained (compare Chapter 6.2). When the fiscal duties are calculated separately, they contribute with approx. a third to the diesel LRMC.

5.4 Net present value calculation

To finalize a project decision, investment calculations with several parameters can be taken into account. Contrary to the static investment calculation, dynamic models, like the NPV calculation, consider the different dates for payments during the estimated plant lifetime. The formula for the NPV is displayed as follows.

$$C_0 = -I + \sum_{t=1}^{T} (CF_t) \cdot (1+i)^{-t}$$

The present value at a certain point in time (period 0) (C_0) is calculated by aggregating the initial investment (I) and the annual cash flows (revenues minus expenses) (CF_t), which are discounted with the calculatory interest rate (i). This calculatory interest rate is influenced by the interest rate for credits and the risk expectations of the investor. If the result amounts to greater or equal to 0, the investment should be done as the investor will receive the invested money including the assumed interest back over the calculated project lifetime. If the value is negative the investment should not be accomplished (Ebert et al. 1994).

The following calculations are based on the investment analysis of Wellinger (2009). The values (investments, reinvestments, O&M costs, fuel costs for the diesel generator, PV insurance) are gained from the previous cost analyses in Chapter 5.1. and 5.2. Besides the initial investments, the avoided costs for the grid-connection with an assumed value of 3,000.00 € are considered. The plant lifetimes are set with 20 years. As both systems are not grid-connected no revenues for the energy sale are created. Revenues are a prerequisite for the NPV calculation otherwise the calculation would always lead to a negative result.

For making the results of the analysis comparable, the required annual energy amount (714 kWh) is multiplied by the current price for house electricity to receive a fictive return. The electricity household price (second half-year 2010) of 0.12 €/kWh including all taxes and fees is taken into account (Eurostat 2011). More about the Croatian electricity price models is stated in Chapter 6.3. The occurring costs are provided with different rates of price increase to consider future price developments. The annual costs are deducted from the respective income to receive the annual cash flows. This figure is discounted by 7.70 % based on the Croatian Banks' weighted average interest rates for Kuna credits indexed to a foreign currency (e.g. Euro) in February 2011 (DZS 2011). No additional risk premium is considered.

Both calculations for PV and the diesel engine (compare Annex F) depict a negative NPV as the income (85.68 € in year 1) for the required energy amount (714 kWh) is relatively low compared with the necessary investment and running costs. The development of the cumulative cash flows over the plant lifetime is shown in Figure 6.

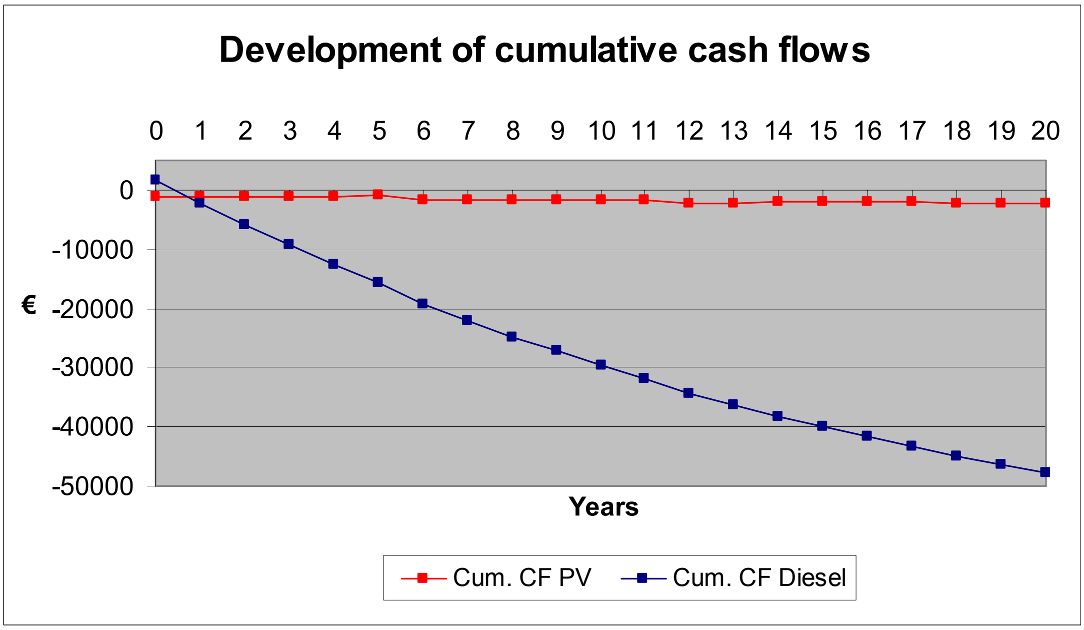

Figure 6: Development of cumulative cash flows for PV and diesel
Source: Author's personal research results (2011)

The PV project with the battery storage generates a NPV of -2,325.87 €, meanwhile the NPV for the diesel generator amounts to -47,769.50 €. From a financial point of view none of the projects should be implemented.

Considering the lack of other energy supply possibilities the more cost-effective PV project should be realised. Further investment calculations, suggested by Aussenegg (2010), are obsolete as the NPV result is negative. The classical payback analysis depicts „*the amount of time it takes for a given project's cumulative net cash flows to recoup the initial investment*". The dynamic approach „*considers time value of money effects*" additionally. Both projects never have a positive result, therewith never reach the payback. The annuity „*is just the NPV transformed into yearly constant cash flows*" and the IRR „*is the constant interest rate that generates an NPV of zero*". These calculations would be feasible, but only a negative result would be depicted. The profitability index is applied to rank several projects with positive NPVs, hence it is not applicable for the above calculated projects.

5.5 Sensitivity analysis

Sensitivity analyses evaluate the effect of one of many input parameters on a single output parameter, while the other input factors are kept constant. This investigation displays the most influencing parameters and reveals the entrepreneurial risk of the single deviations (Weißensteiner 2009). For the two reference projects the following influences on the NPV are analysed:

- Household electricity price
- Calculatory interest rate
- PV investment cost and
- Diesel price, respectively.

The NPV (compare Chapter 5.4.) is a key component for the investment decision and hence taken as the output figure for the sensitivity analysis. The household electricity price influences the earnings over the project lifetime and therewith the economic success of the plants. The annual cash flows of the NPV calculation are discounted with a calculatory interest rate, which depends on the interest rate for credits and the risk expectations of the investor as other investments could be done instead. The PV investment costs and the diesel price are considered to exert influence on the project's success and therewith chosen as parameters for the sensitivity analyses.

The Figures 7 and 8 depict the influences of the input factors in a range from -50 % to +50 % on the NPV, therefore each line has to be regarded separately. The computed sensitivity values are attached in Annex F.

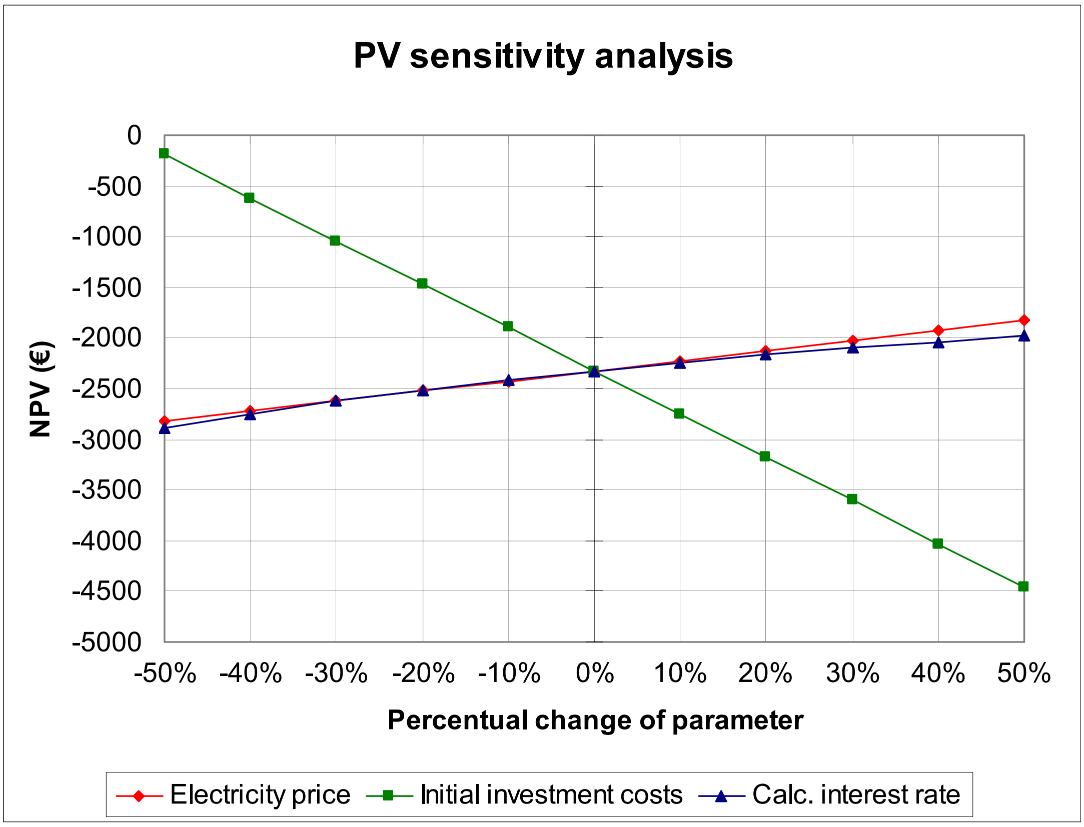

Figure 7: PV sensitivity analysis
Source: Author's personal research results (2011)

Figure 7 reveals the high sensitivity of the NPV on the initial PV investment costs. An improvement at the investment side (cost reduction by 50 %) would make the PV project nearly economically reasonable (-194.07 €). On the other hand, if the investment costs increase by 50 % the NPV result will drop to -4,457.68 €. The two other parameters, the household electricity price and the calculatory interest rate, have only little influence. This is caused by the low energy consumption, even if the electricity price and hence the calculated income increases by 50 % the overall result will not drop below -1,827.67 €. The percentile changes of the calculatory interest rate have no linear influence on the NPV like e.g. the initial investment costs. The non-linear extent is based on the dynamic investment calculation, which considers the time value of money over the complete project lifetime. The term 'time value of money' specifies that future payments are subject to uncertainties like the inflation and therewith the future values are lower than today. The dynamic NPV calculations pays tribute to this circumstance and hence all payments and earnings have to be discounted to the project beginning (period 0) to receive the reduced present value.

The sum of all discounted cash flows, deducted by the initial investment, leads to the final NPV result (Urbatsch 2007). Summarising, the initial investment costs influence the success of the PV project most and make a positive NPV nearly accessible. The sensitivity analysis for the diesel generator displays the following developments.

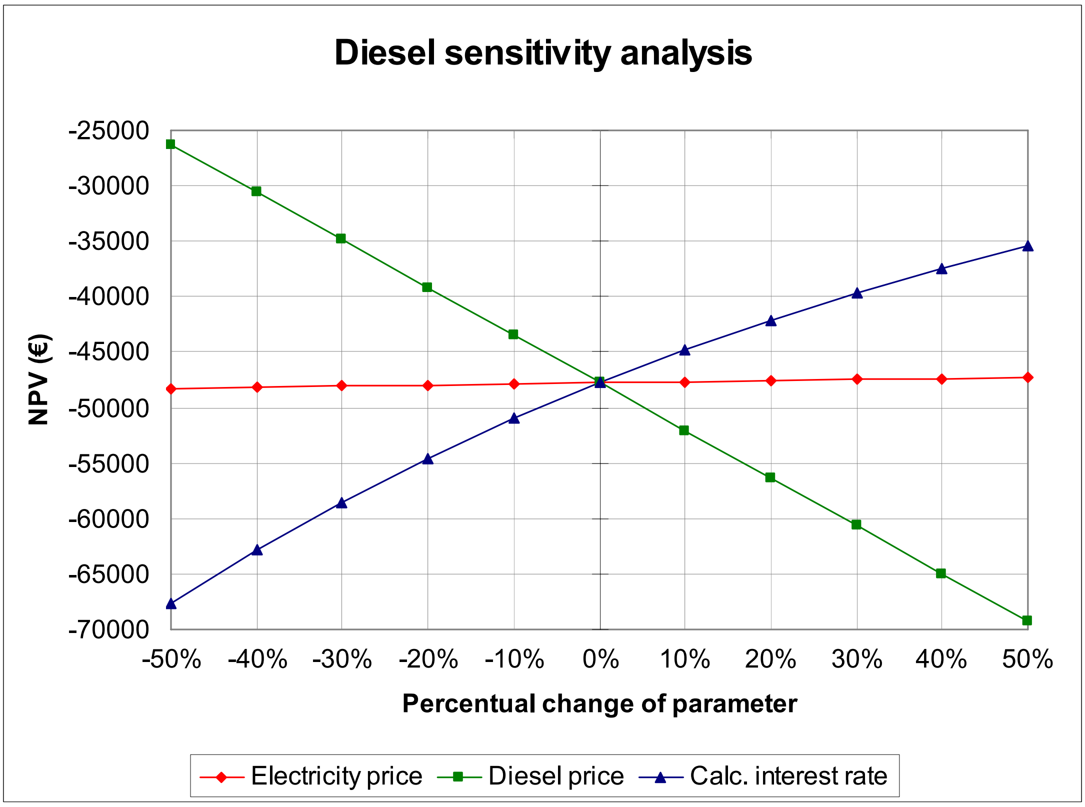

Figure 8: Diesel sensitivity analysis
Source: Author's personal research results (2011)

Again, the electricity household price has only little influence on the NPV, caused by the low annual consumption amount. In the diesel project the calculatory interest rate has greater amplitude reasoned by the high negative cash flows each year. Although the cash flows are reduced by the discounting to the present value, nevertheless the figures stay disproportionately high compared to the PV values. If a high interest rate of 11.55 % is assumed (+50 %), the NPV will drop to -35,400.93 €.

If a return of only 3.85 % (-50 %) is targeted, the final NPV will deteriorate to -67,709.85 €. The most significant sensitivity influence on the reference project has the diesel price. The linear changes in the fuel prices are explainable as the fuel consumption stays stable all over the operation time. If the diesel prices increases by 50 % to 1.88 € per litre, the final NPV will amount to -69,286.26 €. In the case of a positive development, the diesel generator will reach a NPV of -26,252.47 €. A consolidated view indicates that the fuel price has the highest impact, nevertheless the continuous fuel input prevents the attainment of a positive NPV result.

5.6 Comparison between PV and diesel generator

The economical evaluations reveal a negative NPV for both projects over the project lifetime of 20 years (compare Chapter 5.4.). In comparison to the PV project, the diesel generator has the disadvantage of high fuel, O&M and reinvestment costs. The high diesel LRMC of 1.07 €/kWh are caused by the high share (nearly 93 %) of running costs (SRMC) (compare Chapter 5.3.), mainly originated by the costs for the fuel and the fuel transportation to the island. This unsustainable electricity production facilitates a conscious decision for PV as the LRMC (0.65 €/kWh) are significantly lower than for diesel. The main share of the PV costs is allocated to the initial investment (65 % of LRMC), meanwhile the SRMC are mainly influenced by the battery reinvestment costs (more than 91 % of SRMC).

A sensitivity analyses for both projects revealed the dependence on the initial PV investment costs and the diesel fuel price, respectively. The parameter household electricity price is negligible in both cases. The calculatory interest rate influences mainly the diesel generator as high annual cash flows arise which have to be discounted. Besides the economical aspects, the environmental impacts of the combustion processes have to be considered. In a complete diesel combustion process (λ = 3) (compare Chapter 2.7.), one litre of diesel is burned together with three times 14.50 kg air (3.30 kg O_2 + 11.20 kg N_2) to

- 3.20 kg CO_2 (7.17 %)
- 1.20 kg H_2O (2.69 %)
- 6.60 kg O_2 (14.80 %) and
- 33.60 kg N_2 (75.34 %) (Tschöke 2007).

De facto, the combustion process is not completed so the above mentioned values are not reached as not all oxygen is burned and additional residues originate. The Table 9 depicts the percentage shares of the occurring substances:

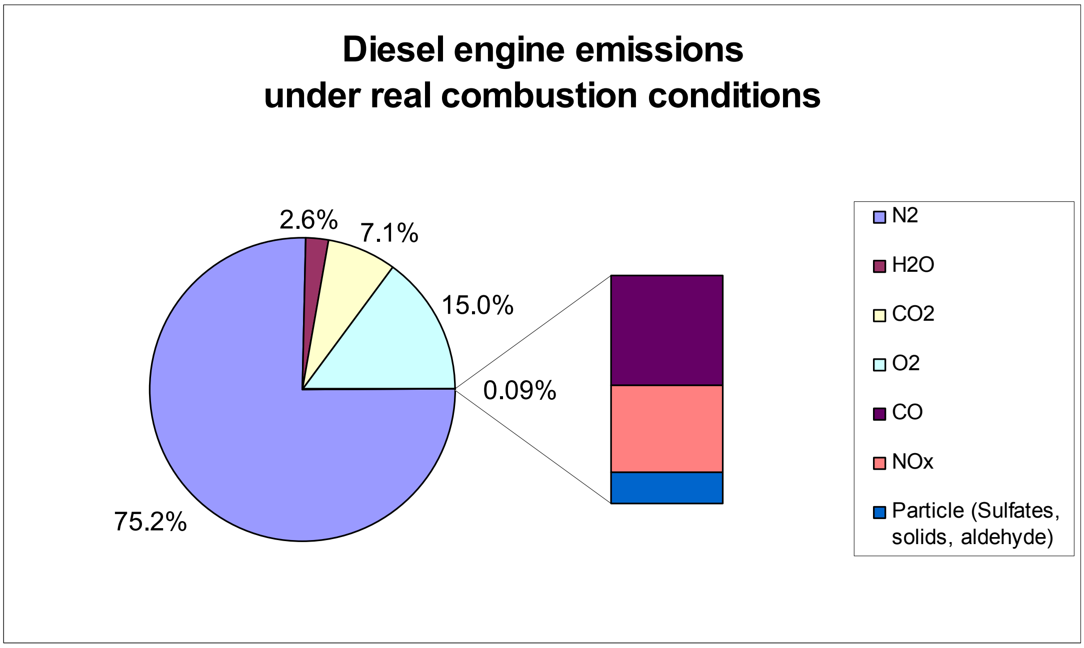

Figure 9: Diesel engine emissions under real combustion conditions
Source: Tschöke (2007)

For further calculations a value of 3.17 kg CO_2 (7.10 %) per kg diesel is considered. The toxic substances, such as carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO_2), hydro carbons (HC) and particulate matter, amount to only 0.09 % or 40 g per kg diesel, but their harmful consequence on the human health and the environment are proven (Tschöke 2007).

Following the above mentioned values, the reference diesel generator (3 kW power output per hour, 1,800 operation hours, hourly fuel consumption of 1.20 litres, 800 litres diesel for transportation) has a fuel consumption of 0.55 litres per produced kWh (0.40 litres diesel for electricity production plus 0.15 litres diesel for the transport). Multiplied with the CO_2-emission value of 3.17 kg CO_2/kg diesel, 1.74 kg CO_2 and 22 g of toxic substances per kWh electricity are produced. To facilitate the procedure, kilograms and litres are set equally. As the diesel engine's manufacturer Rotek does not provide precise emission values, only the above calculated CO_2-amount is compared with the PV value.

The PV emissions are based on the GEMIS-Program of the Institute for Applied Ecology (2010). The whole life cycle of the power plants including transports and material is taken into account, only the disposal and recycling of the power plants are not investigated. In the case of PV, mono-, poly-crystalline and amorphous modules are analysed. Analogously to the reference project, poly-crystalline modules are compared with the diesel generator.

The PV energy production causes 114 g CO_2/kWh (Institute for Applied Ecology 2010) and therewith only nearly 7 % of the diesel emissions. The air pollutants emissions (SO_2, NO_x and particulate matter) are insignificant (total amount of 0.27 g/kWh). The high CO_2-value of the PV modules is caused by the high energy input for the production processes, especially the silicon production (Lippitsch et al. 2009). The GEMIS-data were collected in the year 2005. In the mean time huge efforts have been made, like the further development of the thin-film technologies requiring only a small fraction of the required semiconductor material or improved crystalline production procedures (compare Chapter 2.1.). Therefore, further emission reductions in the future can be expected.

Table 23 highlights the advantage of PV compared to diesel at the production of one kWh, during one year and over the complete project lifetime of 20 years.

Table 23: Comparison of emission output diesel and PV
Source: Author's personal research results (2011) based on Tschöke (2007) and Institute for Applied Ecology (2010)

Emission output diesel - PV							
Electricity production	**Emissions**	**kg/kWh**	**%**	**kg/Year**	**%**	**kg/Plant lifetime**	**%**
Diesel	CO_2	1.74		9,417.60		188,352.00	
	Toxic substances	0.02		118.80		2,376.00	
PV	CO_2	0.11		114.94		2,298.88	
	Toxic substances	0.00		0.37		7.46	
Emission reduction by PV	CO_2	-1.63	93.46	-9,302.66	98.78	-186,053.11	98.78
	Toxic substances	-0.02	98.32	-118.53	99.69	-2,368.54	99.69

An emission reduction of more than 90 % per produced kWh with the PV system compared to the diesel generator is remarkable. The reduction amounts will get even better if the annual and overall emissions are regarded. The diesel generator produces annually 5,400 kWh (1,800 operation hours by 3 kW continuous output), consequently the exceeding energy amount causes higher emission values.

In absolute numbers, annually more than 9,300 kg of CO_2 and 118 kg of toxic substances can be saved by the PV plant. Over a project lifetime of 20 years, the reduction reaches approx. 186 tons of CO_2 and approx. 2.37 tons of toxic substances.

In the ecological context, the utilisation of dangerous substances in the production of PV modules has to be mentioned. An article in the magazine 'Neue Energie' (Rentzing and Heup 2010) lists different hazardous materials like trichlorsilane, fluor, hydrofluoric and nitric acid which are used for the cell and wafer fabrication. In the thin-film-production poisonous semiconductor materials like cadmium are employed. The mentioned substances are dangerous for humans and the environment, as they contaminate water or damage the ozone layer. Therefore they are only applied in closed cycles. Apart from the production, the recycling of PV modules will gain in importance in the future. Currently it is not clear how long the PV modules will operate. Producers guarantee a lifetime of at least 20 years. According to estimations (Heup 2010) the annual return of modules could amount to 35,000 tons in the year 2020. PV modules contain poisonous substances as well as valuable materials like silver. The avoidance of environmental contamination through improper disposal and the recovery of recyclables are the motivation for establishing a recycle system like 'PV cycle'. More information about this European initiative is provided online (www.pvcycle.org).

In the frame of the energy production via diesel generators a careful handling of the fuel and the motor oil has to be guaranteed. Also the careful disposal of the waste oil, the exchanged spare parts and the replaced engine after the operation time is obligatory.

Another aspect is the sound level of the diesel generator. Rotek (2007) states a volume of 96 decibel in four metres distance. Langguth (2011) points out that a steady level of 85 decibel can already lead to serious hearing damages. To avoid negative consequence on the health of the inhabitants the diesel generator should be placed in a separate, with noise abatement measures equipped shed. At the PV plant the inverter generates noise too, but with max. 35 decibel the negative influences are negligible (Siegfriedt n.d.). So the acoustic level corresponds to the household noise level and ranges far below the critical level.

In summary can be said that the advantages of the PV plant outweigh those of the diesel generator. Only at the stage of the initial investment the diesel plant seems to be more attractive. Taking the high running costs and emissions into consideration this view is transferred into the opposite.

5.7 Comparison between PV and household electricity prices

After the direct comparison of the two reference plants, an additional analysis between the PV project and the Croatian household electricity prices is conducted. The Croatian HEP Group, Hrvatska Elektroprivreda, has been the responsible electricity company for electricity production, transmission and distribution, heat supply and gas distribution over several decades. According to various law amendments an unbundling into separate companies was accomplished. Despite the unbundling, the HEP group is still the dominant entity on the market (Kulišić 2010b).

The HEP ODS is the national electricity supplier with the obligation to provide energy supply service at a regulated price (HEP n.d. a). The electricity prices for households in Croatia are bounded to four different tariff models, which differ by the applied meter (single-tariff, multi-tariff, pre-payment meter) and the consumption pattern (amount of required energy, time of consumption (day and night tariff)) (HEP n.d. b). In 2008 more than 2 m. low voltage metering points for households were installed, the average energy consumption amounted to 3,140 kWh (HERA 2009). In the same year the largest consumer group (6,711 GWh) within the overall final electricity consumption (16,137 GWh) was presented by Croatian households, as they consumed nearly 42 % of the electricity (IEA 2011).

To make the tariff and consumption structure comparable to other European countries the Croatian data is incorporated in Eurostat's methodology. Eurostat, the statistical office of the European Union, surveys every half-year the electricity prices for the member states and the candidate countries; Croatia provides its data since the year 2005 (Eurostat 2011). Evaluations of the electricity price development and future scenarios are performed in Chapter 6.3.

For the comparison with PV the average price in the second half-year 2010, i.e. 0.12 €/kWh incl. all taxes and fees, was considered. In the European ranking including the 27 member states and the candidate countries, Croatia ranges in the lowest price segment. Only Romania, Latvia, Estonia, Bulgaria and Bosnia and Herzegovina offer cheaper electricity prices for households. The average electricity price in the 27 EU countries amounts to 0.17 €/kWh (Eurostat 2011).

Considering the Croatian and European household electricity prices, the computed PV LRMC of 0.65 €/kWh are far away from these values and cannot compete with the national electricity suppliers' prices.

The calculated NPV for the PV plant over 20 years shows a negative result of -2,325.87 €. The initial investment for the PV system of 2,698.40 € is cheaper than the assumed grid-connection costs of 3,000.00 €. As the battery system requires an additional capital expenditure of 1,565.21 €, the overall PV expenses exceed the conventional grid-connection. The in Chapter 5.5. conducted sensitivity analyses reveals the low influence of the household electricity price on the two reference projects caused by the low consumption. If greater energy amounts were necessary, the computed development would have greater amplitude.

Analogous to the previous comparison with the diesel generator, the environmental aspects of the electricity production are considered. As analysed in Chapter 3., the Croatian electricity production is dominated by hydro power (52 %), followed by thermal power plants (39 %) (Kulišić 2010b). According to the Croatian Energy Institute Hrvoje Požar (EIHP 2010) 6.70 m. tons of CO_2 were emitted during the electricity production in the year 2008, one third of the Croatians overall CO_2-pollution (approx. 20 m. tons of CO_2). The other investigated pollutants caused by the electricity production summed up to

- 25,210 tons of SO_2
- 9,802 tons of NO_x
- 958 tons of particulate matter in the year 2008 (EIHP 2010).

Remembering the above share of nearly 42 % of residential electricity consumption, the private sector was responsible for approx. 2.81 m. tons of CO_2, 10,588 tons of SO_2, 4,117 tons of NO_x and 402 tons of particulate matter.

To elaborate a comparison between PV and the national electricity production, the most common fossil fuel source in Croatia, natural gas, is taken into account. The national thermal power plants use 64 % gas (1,076 MW), 18 % coal (302 MW) and 18 % fuel oil (303 MW) (EIHP 2010). To obtain workable figures for the time horizon of one year and the complete plant operation time, the fossil fuel emissions for the annual energy consumption of the reference house are investigated.

Table 24: Comparison of emission output gas and PV
Source: Author's personal research results (2011) based on Institute for Applied Ecology (2010)
[3]

Emission output gas - PV							
Electricity production	**Emissions**	**kg/kWh**	**%**	**kg/Year**	**%**	**kg/Plant lifetime**	**%**
Natural gas	CO_2	0.40		285.60		5,712.00	
	Toxic substances	0.00		0.51		10.20	
PV	CO_2	0.11		115.37		2,307.36	
	Toxic substances	0.00		0.37		7.40	
Emission reduction by PV	CO_2	-0.29	71.50	-170.23	59.61	-3,404.64	59.61
	Toxic substances	0.00	47.89	-0.14	27.45	-2.80	27.45

Table 24 presents the GEMIS-emission values for the electricity production with poly-crystalline PV systems and thermal power plants firing natural gas. The pollution by natural gas is considerably lower than those by diesel, nevertheless produces the PV plant nearly 72 % less CO_2 and nearly 48 % less toxic substances than the gas power plant. The annual PV electricity production (1,012 kWh) is compared with the annual household energy consumption (714 kWh). The PV's advantage is slightly reduced over time, caused by the unused surplus PV electricity production. During one year approx. 170 kg of CO_2 (-59.61 %) and 140 g of the toxic substances SO_2, NO_x and particulate matter (-27.45 %) can be saved. Over 20 years operation time the amount reaches 3.40 tons of CO_2 and 2.80 kg of toxic substances.

Summarising, the centralised energy supply by the national utilities brings economical benefits to the costumers. The PV production costs for one kWh are currently more than five times higher than the household electricity prices. In the case of the reference project the low demand reduces the significance of this aspect. The investment of the PV plant without the battery systems is competitive with the price for a new grid-connection.

For the ecological analyses the current Croatian electricity production structure, mainly based on gas, was investigated. The emission reductions are lower than compared to diesel, nevertheless the PV plant scores at this point. Finally, it has to be mentioned, that caused by the exposed position of the Kornati archipelago a conventional energy production will not be feasible in the long run. Therefore, the diesel generator is currently the only reasonable conventional energy production alternative.

6 Future scenarios and potentials

After the investigation of the current electricity supply possibilities and their economic and ecologic impacts, the evolution of the market situation since the year 2008 is observed. On this basis, future scenarios are developed to answer the question if grid-parity between PV and the household electricity prices will be reached until 2030. The term grid-parity describes the competitiveness between the electrical generating costs with PV and the utility prices (Fechner 2010). In this context, the relation between PV and the diesel LRMC and their prospective development are also investigated.

6.1 Development and scenarios of PV prices

The PV trend during the last two decades is a track record. For example, from 1995 to 2009 the German PV system prices dropped by nearly 60 % (López-Polo 2010). The learning curve shows a price reduction of approx. 20 % per doubling of the production volume (Fechner et al. 2007, IEA 2000). In the last years PV systems got an additional boost, caused by increased experience resulting in higher efficiency degrees, improved production methods and an enormous enlargement of the production facilities. Simultaneously, changes in the support measures of several countries, e.g. Spain or Germany, and the financial crisis induced insecurities at the investor’s side. Hence project delays and a resulting overproduction occurred with the consequence of an enormous price reduction (EPIA 2010, Solarbuzz 2011a).

Despite these mitigating factors the year 2010 was really successful for the PV industry: „*Capacity additions grew from 7.20 gigawatts (GW) installed in 2009 to 16.60 GW in 2010. The total installed capacity in the world now amounts to around 40 GW, producing some 50 terawatt-hours (TWh) of electrical power every year.*" (EPIA 2011b).

According to a cell production survey of the journal Photon International (Hering 2011), the PV development is facing bright future prospects as the market is further expanding and production capacities for modules and inverters are still enlarged. Especially, the multi-crystalline cell production will further expand. In the year 2010 these cells accounted for more than the half of the annual output. On the producers side it is obvious, that Chinese and Taiwanese module producers are gaining more and more dominance in the market, taking shares from the German and Japanese manufactures (Hering 2011). An additional factor for an increasing PV deployment is an improved module's efficiency, which is forecasted to reach values of 18 to 23 % for crystalline and 10 to 16 % for thin-film modules in the year 2020 (Solar Europe Industry Initiative n.d.). The most decisive determinant for the future development is the price. The initiative also outlines the following price goals for large-scale turnkey systems in the respective years (Solar Europe Industry Initiative n.d.):

- 2010: 2.50 to 3.50 €/Wp
- 2015: 2.00 €/Wp
- 2020: 1.50 €/Wp

Calculating with an average value of 3.00 €/Wp in the year 2010, a cost reduction of 50 % over 10 years or an annual decrease of 5 % are expected. The European PV Technology Platform (2010) anticipates that this rate will remain stable over the next two decades.

With the above mentioned price range in the year 2010, the computed price for the PV reference plant can be validated. The price of 3.60 €/Wp for this small-scale PV system is still competitive. The deviation from the European prices is caused by country-specific market influences and administrative obstacles (compare Chapter 3.), which have to be diminished during the next years to foster a higher PV implementation.

The evaluation of the development from 2008 to 2030 is done on basis of the reference project's LRMC calculation (€/kWh), considering real prices in the first half-year 2011. The costs for the years 2008 to 2010 are estimated with the help of a retrograde calculation, as no comparable values for Croatian off-grid plants are available. An annual price decline of 5.00 % is assumed and added in to receive the previous year's value. For the time span 2012 to 2030 the following two scenarios are supposed:

A) The annual price reduction remains constant at 5.00 % until the year 2030.
B) The above mentioned price reduction of 5.00 % and an improvement of the module efficiency rate, by a conservative value of 5.00 %, are assumed. Currently, the reference project is calculated with a module efficiency of 12.20 % and an overall performance of 10.59 % (PR = 86.78 %) in the year 2011. For this scenario an increase of 5.00 % in the module efficiency until the year 2030 is converted is assumed. The new efficiency degree of 17.20 % is converted with the PR to a system efficiency degree of 14.93 %. For the evaluation of the efficiency until 2030 a linear increase is assumed.

The assumptions are entered in the LRMC-calculation (compare Chapter 5.3.) and the development for the years 2008 to 2030 is depicted in Figure 10. The complete calculation is inserted in Annex G.

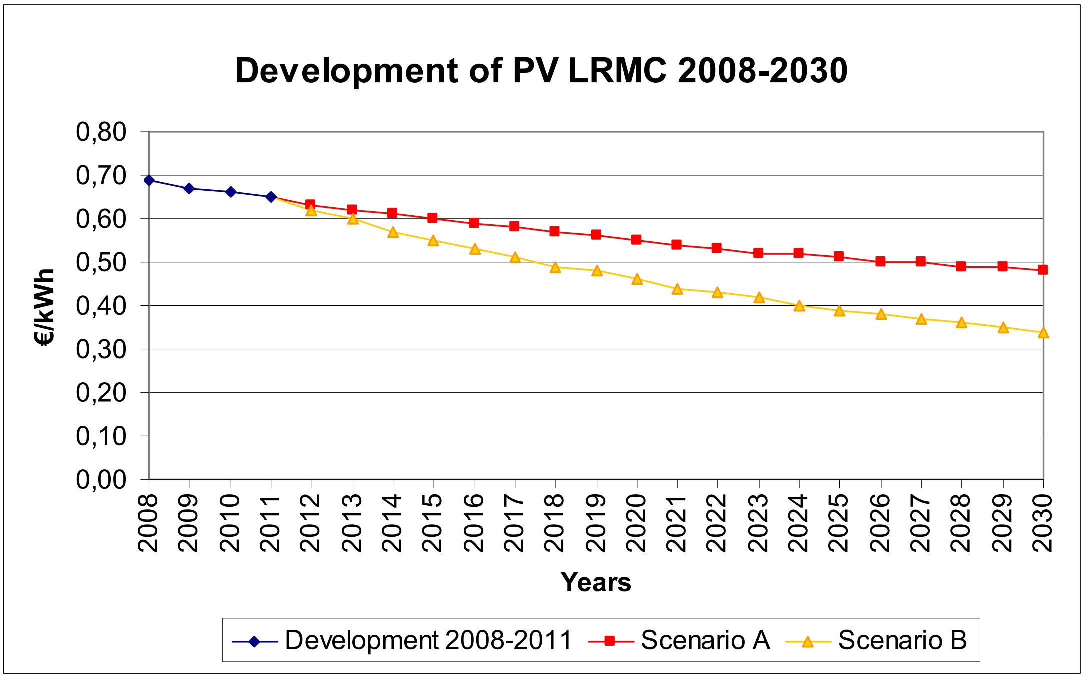

Figure 10: Development of PV LRMC 2008-2030
Source: Author's personal research results (2011)

Figure 10 makes clear that the LRMC for this type of PV plant (small-scale, with large battery storage) will not decrease below 0.48 €/kWh in scenario A. The additional efficiency improvement in scenario B leads to a value of 0.34 €/kWh in the year 2030. It becomes obvious, that not only the PV investment costs are the ultimate measure for competitive electricity prices. Further steps, like the reduction of the battery cost and of the BOS, have to be taken to shift the LRMC into a more competitive price range. The term BOS is the abbreviation for 'Balace of System' and comprises all components and services, except for the PV modules, which are necessary to put the PV plant into operation. Examples for BOS are the inverter, the cabling, the mounting racks, etc. (Colexon n.d.).

6.2 Development and scenarios of diesel prices

The development of the diesel prices since 2000 was driven by „*tremendous price increases for fossil fuels on the global market and high price volatility. […] The scale of daily oil price variations has been constantly increasing since the start of the new millennium.*" This statement of the GTZ (2009) is substantiated by the specific Croatian figures. From year 2000 to year 2008 the price for the Croatian brand 'Diesel' increased by 77 % from 4.78 Kn/l to 8.50 Kn/l (EIHP 2010), which implies an annual growth rate of nearly 10 %.

„*This higher volatility in oil prices as well as the new peaks in prices observed in mid-2008 call for a reassessment of fuel price policies, especially regarding the adjustment of national retail prices and the question of taxation.*" (GTZ 2009). This general trend was also found in Croatia. While the average price for the Croatian brand 'Euro diesel' amounted to 1.20 €/l (8.63 Kn/l, Kn/€ exchange rate of 7.22) in the year 2008, the price dropped by more than a fifth to 0.93 €/l (6.79 Kn/l, average Kn/€ exchange rate of 7.34) in the year 2009 (EIHP 2010, DZS 2010).

The price development since 2007, including current price levels, is monitored e.g. by the German online database Gasoline-germany.com. The therein stated prices coincide with the above presented values. The value of 1.25 € per litre diesel denoted in June 2011 is taken into account for further calculations (Gasoline-germany.com 2011).

The consideration of the Croatian domestic fossil resources emphasises the dependency on the international market and therewith the high price volatility. In the year 2009 only 19 % of the refined crude oil amount (0.77 m. tons) was produced domestically. Approx. one quarter (1.22 m. tons) of the gross refinery intake (4.85 m. tons) was converted to diesel oil. 20 % of the produced diesel amount (0.24 m. tons) were exported, meanwhile additional 0.52 m. tons were imported from foreign countries (EIHP 2010).

The international dependency influences the Croatian fuel prices like in other European countries. The 27 European member states publish their fuel prices and the pricing at the European Energy Platform 'Energy.eu' (2011). Although Croatia is an EU candidate country, these values are not released. Several official documents (laws, directions and decrees), announced in the official gazette Narodne novine, provide the legal basis for this calculations (Narodne novine 2006a, Narodne novine 2006b, Ministarstvo Financija 2009).

The prices of petroleum products depend on raw material, import and processing related expenses and on fiscal charges. The basic price is determined by the exchange price, the current Kn/USD exchange rate and the customs duty (approx 2 % on the purchase price) for bringing the fuel into the country. Additionally, a maximum margin of 0.60 Kn/l (0.08 €/l at an exchange rate of 7.30 Kn/€) and a supplementary processing fee of 120 Kn/t (approx. 0.02 €/l) are charged (Narodne novine 2006b).

The fiscal laws regulate the excise duties, which have to be paid for the consumption of special goods, e.g. alcohol, cigarettes, fuels, and the regular value added tax (VAT). The excise duty for diesel motor fuels amounts to 2,050 Kn/1,000 l (0.28 ct/l). The VAT is charged with 23 % of the net retail price (Ministarstvo Financija 2009). Calculating with a retail price of 1.25 €, the VAT amounts to 0.23 ct/l. Hence the fiscal expenses (excise duty, VAT) account for 40.80 % of the Croatian retail price. Despite all public discussions and the resulting political awareness about the topic fuel prices, the costs have been escalating again. In June 2011 the diesel price reached 1.25 €/l (Gasoline-germany.com 2011). According to the initially mentioned price development of nearly 10 % per year since beginning of the millennium (GTZ 2009) are two possible long-term scenarios until 2030 designed:

A) An annual price increase of 2.50 % on basis of the value of June 2011.

B) A yearly accumulation of 4.00 % on basis of the price level in June 2011.

The assumed diesel prices are entered in the LRMC-calculation (compare Chapter 5.3.) and the development for the years 2008 to 2030 is displayed in Figure 11. The subjacent calculation is added in Annex G.

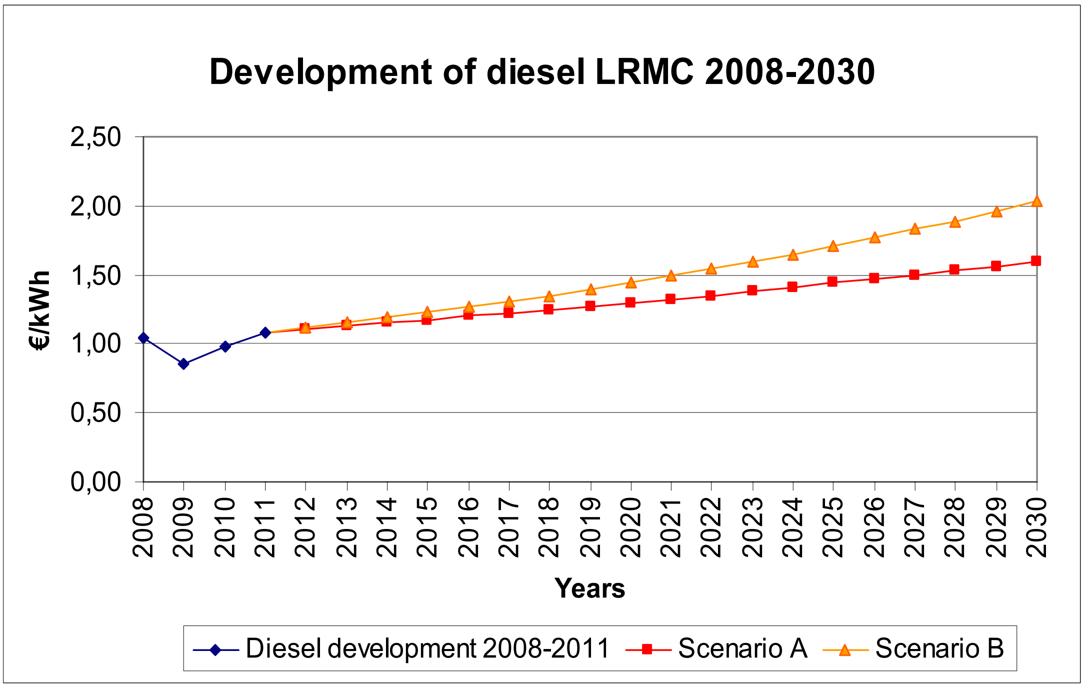

Figure 11: Development of diesel LRMC 2008-2030
Source: Author’s personal research results (2011)

Figure 11 shows that the LRMC are highly dependent on the fuel prices. An annual increase of 2.50 % leads to a diesel price of 2.00 €/l and to costs of 1.60 €/kWh in scenario A until the year 2030. The assumption of 4.00 % yearly increase in the same time span generates a diesel price of 2.63 €/l and energy production costs of 2.03 €/kWh.

6.3 Development and scenarios of electricity prices

Analogously to the development of the oil price the household electricity prices have been subject to a steady increase since the beginning of this decade. Although the Croatian prices are situated at a low level compared to other European countries (compare Chapter 5.7.), the annual increment is obvious.

As basis for further scenarios serve the Croatian household gross electricity prices for the years 2008 to 2010 published by Eurostat (2011). For this purpose also the price structure is assessed. Figure 12 displays the portion of costs for customers with a consumption of 2,500 to 5,000 kWh per year on basis of the household prices in the second half-year 2009.

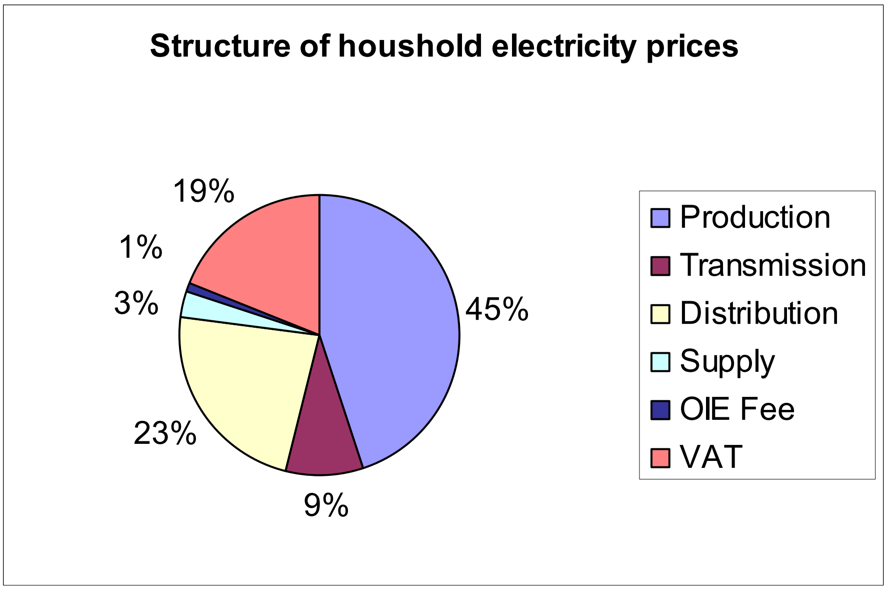

Figure 12: Structure of household electricity prices
Source: Hera (2010b)

Based on the analyses of Hera (2010b), nearly half of the household electricity costs is allocated to the production and 19 % to the tax expenses. The delivery (transmission and distribution) to the consumer amounts to another 35 %. The smallest proportion (1 %) is designated for the OIE (obnovljivi izvori energije – renewable energy sources) fee, „*a special charge for promotion of electricity production from renewable sources*" (HEP n.d. a.).

For the estimation of the future scenarios different studies are surveyed. E.g. Capros (2007), Bulteel and Capros (2009), Carpos et al. (2010), EWI/Prognos (Lindenberger et al. 2006), Deutsche Bank Research (Auer 2010), Purwanto et al. (2004) or the 'World Energy Outlook' by the IEA (2009) investigate past trends, the prevailing energy conditions and different influences, like scarcity of resources or the pricing of CO_2-certificates. Resulting from these factors different scenarios are defined and their impacts assessed. The main aspects, especially concerning electricity, are summarised briefly as follows.

Despite the global crisis, the worldwide increasing demand for electricity still exists and will continue for the next decades. The demand growth rates depend on the respective region (e.g. high demand in emerging Asian countries, lower demand in well-developed OECD countries). The availability and a possible scarcity of resources exert great influence, like the dependency of regions on imports and therewith a high sensitivity on price increases. Also the suggested electricity production methods are influencing the scenarios. The spectrum reaches from unchanged confidence in fossil-fuel technologies, a further increase of nuclear power, the fostering of technologies like CCS or the change of paradigm to renewable energy technologies and stronger energy efficiency. Emphasis is also put on CO_2-emission allowances and their pricing. The effects of all this impacts on the electricity prices and finally at the customer are evaluated to a greater or lesser extent. It can be concluded that this will result in an increase of the electricity prices within the next decades but the estimations diverge.

The lowest increase in the surveyed analyses state Purwanto et al. (2004) with reference to the European TRIAS research project. The assumed increase of the average electricity price of the 27 EU countries amounts only to 4 % (0.09 % p.a.) over a period of 45 years (2005 to 2050). The analysis of EWI/Prognos (Lindenberger et al. 2006) defines a reference scenario with an electricity price increase for households of 8 % from 2000 to 2030 (0.27 % p.a.). Additionally the correlation between the oil and gas prices and the electricity prices are investigated. A rise in these prices elevates the electricity production costs, but does not influence the grid-costs, the taxes and fees. Therewith the consumer electricity prices rise by 10 % over 30 years (0.33 % p.a.).

The studies of Capros (2007) and Bulteel and Capros (2009) comprise the European energy policies and follow a baseline scenario of the year 2007. All resulting variants anticipate a low electricity price increase. In the worst case an annual increase of 1.32 % p.a. is calculated for the years 2005 to 2030 (Base Index 2005 = 100, Supply Scenario Index 2030 = 133).

A change in the European RES promoting policies including significantly amended carbon reduction policies led Carpos et al. (2010) to correct the assumptions and to set up a new baseline scenario referring to the year 2009. This scenario includes expenses for grid-expansion and grid-controlling measures, increasing fuel prices, costs for auctioning of carbon, as well as higher capital and O&M costs. The reference scenario, as a second possibility with an even more progressive RES approach, shows a similar price development as the baseline scenario until 2020. In a longer time span until 2030 the reference scenarios gains leverage because of the higher RES deployment on the one hand and reduced auctioning and fuel costs on the other hand.

In the baseline scenario (baseline 2009) the increase of the after-tax electricity supply amounts to over 44 % over 25 years (2005 to 2030) or 1.76 % per year. In the upgraded reference scenario the price increases by approx. 40 % (1.59 % p.a.) in the same timeframe.

The highest price incline in the observed studies states the Deutsche Bank Research (Auer 2010) by assuming an annual increase of 4.00 %. A possible reason for the increasing rates in the latest studies, in the view of the author, are explosive developments of input factors, like the oil price, fast changes of legal and financial framework conditions and especially the gained experience and hence improved forecast models. To gain a deeper insight in the wide-ranging topic of energy scenarios refer to the above mentioned studies.

The following growth rates are added to the household electricity price of 2010 to receive the future electricity scenario prices (compare Annex G). The price development for the years 2008 to 2030 is depicted in Figure 13.

A) A steady annual electricity price increase by 1.00 % from the year 2010 to the year 2030.
B) A rise in prices by 2.50 % per year in the same time span caused by a fast economic growth and accompanied by an increase of the energy demand in Croatia.

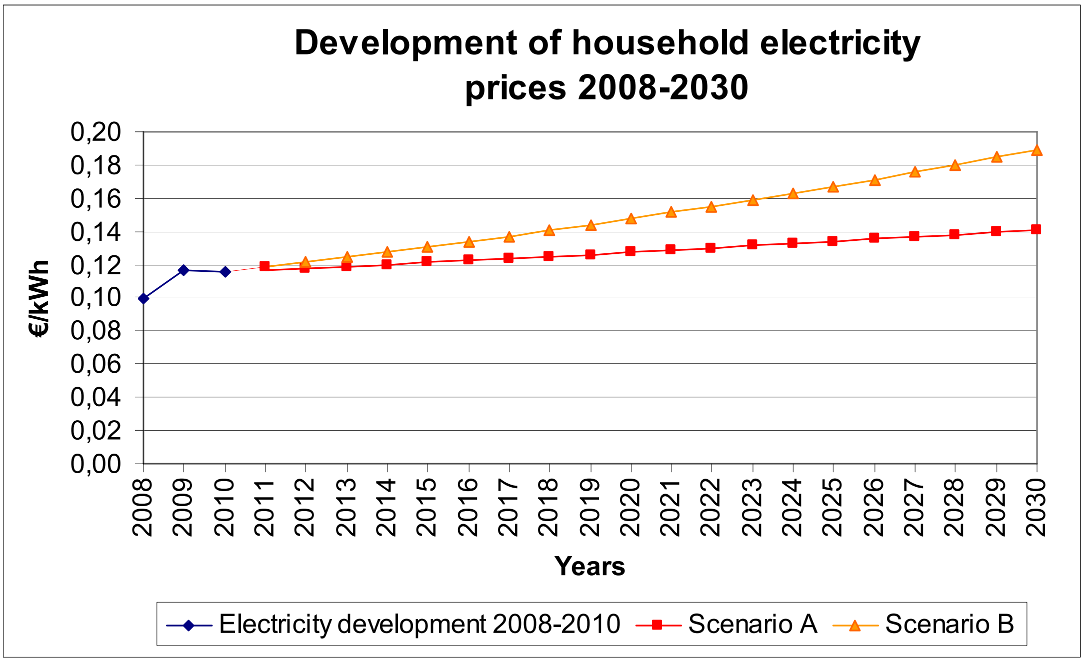

Figure 13: Development of the household electricity prices 2008-2030
Source: Author's personal research results (2011) based on Eurostat (2011)

Even in scenario B the level of 0.20 €/kWh is not achieved. The development of the household electricity prices is calculated to reach the value of 0.14 €/kWh in scenario A and the value of 0.19 €/kWh in the progressive scenario B.

6.4 Comparison between the assumed scenarios

A comparison between all previous developments and the assumed scenarios for the years 2008 to 2030 is performed in Figure 14.

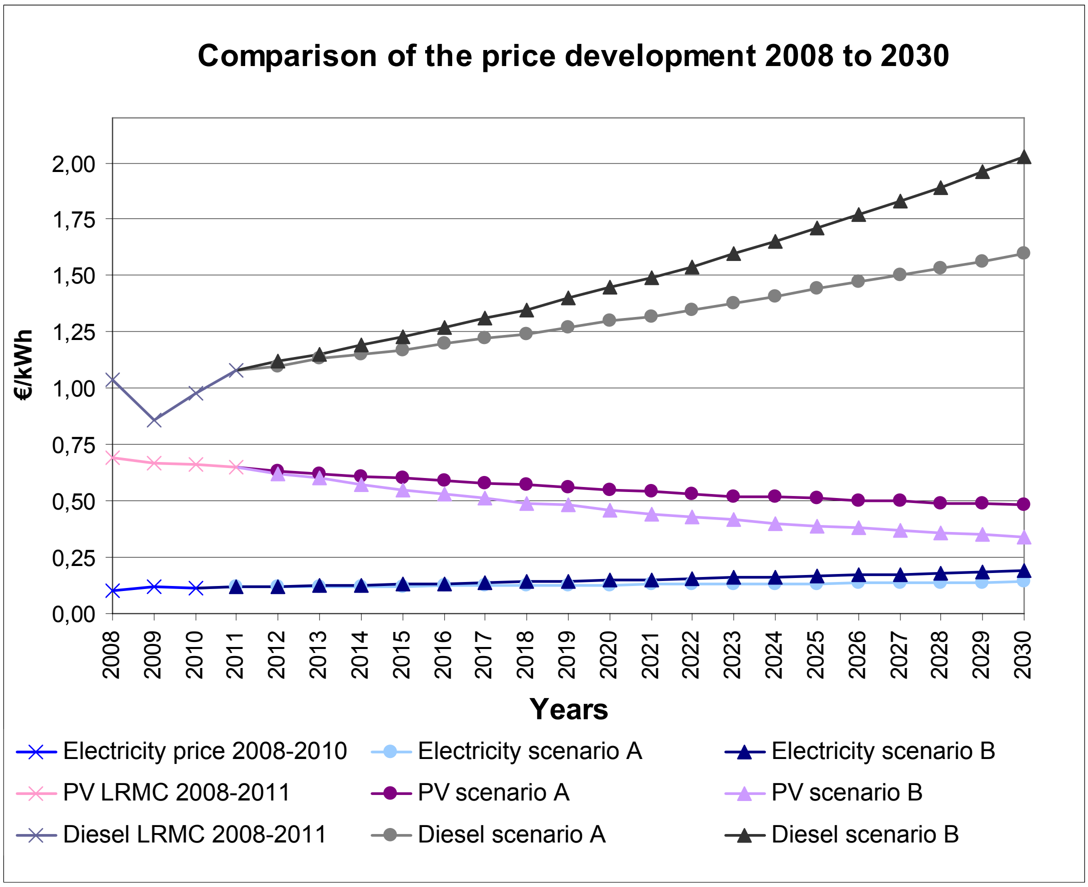

Figure 14: Comparison of the price development 2008-2030
Source: Author's personal research results (2011)

Figure 14 presents the computed developments of the household electricity price and the PV and diesel LRMC. It becomes clear that none of the PV scenarios will reach the grid-parity with the household electricity prices until the year 2030. Meanwhile in direct comparison of the available energy sources on the Kornati islands, the PV costs are constantly cheaper than the diesel energy production costs. In the moderate scenarios A the diesel electricity productions costs amount to more than the threefold of the PV costs in the year 2030. At the end of the progressive scenarios B the diesel costs are nearly six times as high as the PV costs. For remote Croatian areas, like the Kornati archipelago, a small-scale PV plant is already an alternative to the existing diesel generators. Considering the increasing performance and ongoing cost reductions over the years, future potential is given.

6.5 Potentials

The assessment of the technical potentials and the prescribed goals of the Croatian government (compare Chapter 3.) brought up that PV is not promoted explicitly by the Croatian state although the prerequisites (e.g. sun radiation) are given. In contradistinction to the governmental position stand the calculated benefits of the small-scale PV plant compared with the diesel generator in remote areas without grid-connection.

In the following chapter the economical and ecological aspects, first for the archipelago Kornati and afterwards, to a bigger extent, for a higher number of Croatian households along the Croatian coast, are evaluated to display the viability and the advantages of such systems.

51 houses are located in the Kornati national park (Nacionalni Park Kornati n.d. b), which are inhabited permanently or infrequently. For the calculation of the saving potential by the implementation of the PV plants, the following assumptions are made.

- The 51 houses are inhabited for 180 days per years
- The investment costs are set equally to the reference diesel engine
- The diesel generators (3 kW nominal power) operate two hours a day
- The O&M costs amount to 150 € per year
- An average diesel consumption of 1.20 litres per hour, in many cases older and less efficient diesel engines will cause a higher consumption
- Weekly transport of the diesel to the houses (25 times per year). The diesel consumption for the transport is equal to the previous calculations (Two ways 20 nm each, the boats run at an average speed of 5 nm per hour with an fuel consumption of 2 litres per hour)
- A diesel price of 1.25 €/l (June 2011) (Gasoline-germany.com 2011).

The diesel consumption of one house amounts to 432 l per year and additionally 400 l for the transport have to be considered. The annual diesel expenses sum up to 1,040.00 €. The above mentioned figures are transferred into the electricity cost calculation in Chapter 5.3.

$$LRMC_{EL\,D} = \left(\frac{\alpha \cdot c_{INV}}{T} \right) + \left(\frac{c_{FUEL}}{\eta_{EL}} + c_{VAR\,O\,\&\,M} \right)$$

$$LRMC_{EL\,D} = \left(\frac{0.10 \cdot (1{,}106.00\,€ + 290.65\,€)}{360\,h} \right) +$$

$$\left(\frac{\frac{360\,h \cdot 1.20\,l \cdot 1.25\,€ + 400\,l \cdot 1.25\,€}{360\,h \cdot 3\,kW}}{0.80} + \frac{150\,€}{360\,h \cdot 3\,kW} \right)$$

$LRMC_{EL\,D}$ = 0.39 + 1.34 = 1.73 €/kWh

Compared to the diesel reference plant (1.07 €/kWh), the LRMC even increase (1.73 €/kWh) as the annual operation hours and therewith the quotient are lower. If the investment costs are subtracted, the SRMC would still amount to 1.34 €/kWh. Compared with the PV LRMC of 0.65 €/kWh, evaluated in Chapter 5.3., each household can save max. 1.08 €/kWh. At the production of 1,080 kWh (3 kW, 360 operation hours), the annual savings per household and for all houses on the Kornati archipelago amount to max. 1,166.40 € and 59,486.40 €, respectively. Over 20 years operation time the monetary benefit reaches 23,328.00 € and 1,189,728.00 €, respectively.

For calculating the ecological potential, the consumed diesel amount (832 l per household) is divided by the produced electricity (3 kW, 360 operation hours = 1,080 kWh) (compare Chapter 5.6.). Hence 0.77 litres of diesel are necessary for one kWh. Multiplying this value with 3.17 kg CO_2/kg diesel, 2.44 kg CO_2 are emitted per produced kWh. In conclusion, 2.64 tons of CO_2 per household and more than 134 tons of CO_2 for all houses in the national park are emitted per year.

Considering the amount of toxic substances (40 g per litre diesel) within this calculation, 33.26 kg of toxic substances per household and nearly 1.70 tons over the Kornati area are emitted per year. In Table 25 the diesel emissions are compared to the arising PV emissions.

Table 25: Emission output in the Kornati national park
Source: Author's personal research results (2011) based on Tschöke (2007) and Institute for Applied Ecology (2010)

Emission output in the Kornati national park				
Electricity production	**Emissions**	**Single house**		**National park**
		kg/kWh	**kg/Year**	**kg/Year**
Diesel	CO_2	2.44	2,635.20	134,395.20
	Toxic substances	0.03	33.26	1,696.46
PV	CO_2	0.11	123.12	6,279.12
	Toxic substances	0.00	0.40	20.38
Emission reduction by PV	CO_2	-2.33	-2,512.08	-128,116.08
	Toxic substances	-0.03	-32.86	-1,676.08

From Table 25 it becomes clear that PV has an enormous emission reduction potential compared to the diesel generators. More than 128 tons of CO_2 and approx. 1.68 tons of toxic substances can be avoided by the PV systems.

The Kornati national park presents only a small section along the Croatian coast. As the Croatian Census 2001 does not survey the number of diesel generators the following assumptions are taken into account:

- According to the Croatian Census 2001 (DZS 2001) 1,877,126 dwellings, including 182,512 houses for vacation and recreation, are registered all over the country.
- For recreational purposes especially the Dalmatian area is popular. It reaches from Zadar in the North down to the border of Montenegro and comprises many islands. Outside the larger cities (e.g. Zadar, Šibenik, Split, Dubrovnik, Kastela) many small and remote houses and settlements can be found along the coastal line (Kroatische Zentrale für Tourismus 2011).
- In the counties Zadar, Šibenik-Knin, Split-Dalmatia and Dubrovnik-Neretva, located in the Dalmatian area, 399,393 houses and thereof 67,830 temporarily inhabited holiday homes (17 %) are located.

Considering these figures, the assumption of 5,000 holiday homes (7.37 % of the holiday homes in the four above mentioned counties or 2.74 % of the overall Croatian holiday homes) with similar energy structure (fluctuating energy demand by irregular inhabitation, no connection to the electricity grid, diesel generator to supply the demand) seems to be realistic.

For further calculations the above mentioned diesel engine assumptions are taken into account (2 hours per day, semi-annual occupation (180 days), 3 kW diesel generator, 1.20 litres hourly diesel consumption, 1.25 €/l Diesel, 150.00 € O&M expenses p.a.). As these houses can be located on islands or along the coast of the mainland, the transport expenses are not surveyed.

Without the transport costs the diesel LRMC drop to 1.15 €/kWh and hence the PV cost saving potential is reduced to max. 0.50 €/kWh (540.00 € p.a.). Transferred to the assumed number of 5,000 households, annual accumulated costs of 2.70 m. € can be saved by the owners by year. The savings over 20 years per household and for the assumed amount of houses amount to 10,800.00 € and 54 m. €, respectively. Additionally, the ecological aspects, depicted in Table 26, have to be regarded.

Table 26: Emission output in the potential Croatian area
Source: Author's personal research results (2011) based on Tschöke (2007) and Institute for Applied Ecology (2010)

Emission output in the potential Croatian area				
Electricity production	**Emissions**	**Single house**		**5,000 houses**
		kg/kWh	**kg/Year**	**t/Year**
Diesel	CO_2	1.27	1,369.44	6,847.20
	Toxic substances	0.02	17.28	86.40
PV	CO_2	0.11	123.12	615.60
	Toxic substances	0.00	0.40	2.00
Emission reduction by PV	CO_2	-1.15	-1.246,32	-6,231.60
	Toxic substances	-0.02	-16.88	-84.40

Each of the houses produces with the diesel generator nearly 1.37 tons of CO_2 and 17.28 kg of toxic substances per year. Extrapolated to the overall number of houses 2.16 m. litres of diesel are consumed and therewith 6,847.20 tons of CO_2 and 84.40 tons of toxic substances are emitted per year. By deploying a PV plant more than 90 % of the emissions can be saved per year. The economical and ecological results should provide an incentive for the house owners to deploy small-scale PV systems for remote houses. An additional measure to limit the use of diesel would be an additional fee for the CO_2-emissions. The European Union already introduced a trade system for CO_2-emission allowances, which is limited to the power and industry sectors currently (IEA 2009).

The estimation about the future price development of these allowances vary (compare IEA 2009 and Capros 2010), so an amount of 50 € per ton CO_2 is estimated. The Croatian state would generate additional revenues of 342,360 € per year with the taxation of the CO_2-emission allowances for the utilised diesel of the 5,000 reference houses. Financial measures can contribute to the future energy development in this region, but more reasonable is the avoidance of CO_2 and other emissions. Especially with regard to the sensitive ecology in the national park and along the Croatian coast further measures (compare Chapter 7.) have to be taken to foster the substitution of diesel generators by PV plants.

7 Conclusion

The work clarifies that the designed small-scale photovoltaic plant with battery storage can substitute and outperform economically and ecologically a diesel generator on the reference location of the Kornati archipelago over the plant lifetime of 20 years and provides a sustainable energy supply for other remote areas in Croatia. A sensitivity analysis reveales the high dependency of the reference plants on the diesel price and the initial PV investment costs, respectively. The continuous fuel input inhibits positive calculations results of the diesel engine. With regard on the potential diesel price development until the year 2030, the diesel electricity production reaches a maximum value of 2.03 €/kWh and therewith a multiple of the PV energy production costs.

Additionally, a comparison with the household electricity prices is performed. The theoretical grid-parity between the reference PV-system and the conventional energy prices is not reached until the year 2030 even when an increase in household electricity prices and a decrease in PV system prices are assumed. Although the grid-parity is not reached, the PV system is still recommended, as no electricity supply by the grid is available at the reference location.

After the assessment of the potentials within the Kornati area, the potential for households on Croatian islands and along the coast is calculated. This work concludes that at least 5,000 Croatian households in the designated area could save 2.16 m. litres of diesel and 6,231 tons of CO_2 and over 84 tons of toxic substances per year by substituting the prevailing diesel generators by new PV systems with battery storage. Besides the ecological aspects the economic benefits are convincing, each household can save 10,800.00 € over the plant lifetime of 20 years by substituting a diesel generator by a small-scale PV-plant.

As Croatia aims for an EU-membership the national targets, e.g. emission reductions, fostering of RES and setting of binding targets, are adapted to the objectives of the 27 EU countries. Regarding the national dependence on fuel and electricity imports, the stronger deployment of PV systems as a local, sustainable, secure, and environment friendly technique is suggested and should be supported by the government. Further measures, like information campaigns, research funds or investment subsidies, should be taken to foster the Croatian PV industry, which is currently underdeveloped. If a serious attempt for reducing the Croatian dependency on energy supplies from foreign countries is made, additionally a change of thinking will be necessary. Scheer (2005) proclaims ten maxims for attaining this liberty, reaching from changes in the rural and urban planning to a serious unbundling of the utilities.

Different actions besides the electricity production have to be taken. Energy saving measures, especially improved house insulations, effective heating devices and the replacement of old energy consuming household devices, have to be targeted. Besides the prevailing ground-mounted and roof-mounted systems, building integrated PV plants have to be considered. More information about this topic with technical and economical aspects and case studies provide Haas et al. (2002).

With respect to the negative consequences of the current energy structure on the environment it has to be emphasised that enormous effort has to be undertaken worldwide to reach 100 % sustainable energy supply provided by renewable energies within the next decades. Otherwise unforeseeable climatic changes will be postponed to the next generation (Nakicenovic 2011). This effort should not be seen as an unbearable burden, but as a new economic chance for industrial nations and as an enormous chance for developing countries (Scheer 2010). Following the words of Stern (2006) „*there is still time to avoid the worst impacts of climate change if strong collective action starts now*“. Small-scale PV plants can contribute to a sustainable approach through its decentralised and modular character and are already competitive to the conventional energy supply in remote areas.

References

Articles and brochures

Hering, G. (2011): Article „Year of the tiger“, Photon International, Number 3, March 11, pp. 186 – 218

Heup, J. (2010): Article „Scherben bringen nicht nur Glück“, Neue Energie – Das Magazin für erneuerbare Energie, Number 3, March 2010, pp. 64 – 67

Kroatische Zentrale für Tourismus (2007): Brochure „Informationen für Nautiker 2007/2008“, Kroatische Zentrale für Tourismus, Zagreb

Rentzing, S. and Heup, J. (2010): Article „Grün, grün, grün …“, Neue Energie – Das Magazin für erneuerbare Energie, Number 3, March 2010, pp. 58 - 63

Schoenherr Energy (2010): Brochure „A basic legal primer to wind power generation“, Schoenherr Rechtsanwälte GmbH, Wien

Books

Antony, F., Dürschner, C. and Remmers, K-H. (2005): Photovoltaik für Profis – Verkauf, Planung und Montage von Solarstromanlagen, Solarpraxis AG, VWEW Energieverlag GmbH and Verlag ’Solare Zukunft’, Berlin, Frankfurt/Main, Erlangen

Ebert, G., Grimm-Curtius, H., Pfeiffer, R., Preißler, P, Wanner, E., Wenzel, G. and Wiese, O. (1994): Kompendium der Betriebswirtschaftslehre, In: Bestmann, U.: Kompendium der Betriebswirtschaftslehre, R. Oldenburg Verlag, München, Wien

Eder, B. and Schulz, H. (2007): Biogas – Praxis, Grundlagen – Planung – Anlagenbau – Beispiele – Wirtschaftlichkeit, ökobuch Verlag, Staufen bei Freiburg

Giesecke, J. and Mosonyi, E. (2009): Wasserkraftanlagen – Planung, Bau und Betrieb, Springer-Verlag, Berlin Heidelberg

Häberlin, H. (2010): Photovoltaik – Strom aus Sonnenlicht für Verbundnetz und Inselanlagen, Electrosuisse Verlag, Fehraltdorf

Häckel, H. (2008): Meteorologie, Verlag Eugen Ulmer, Stuttgart

Haselhuhn, R., Hemmerle, C. and Hartmann, U. (2005): Leitfaden Photovotaische Anlagen, DGS, Deutsche Gesellschaft für Sonnenenergie, Landesverband Berlin Brandenburg e.V., Berlin

Lippitsch, K., Kaltschmitt, M., Schröder, G., Janczik, S. and Wilk, H. (2009): Photovoltaische Stromerzeugung – Ökologische und ökonomische Analyse, In: Kaltschmitt, M. and Streicher, W.: Regenerative Energien in Österreich – Grundlagen, Systemtechnik, Umweltaspekte, Kostenanalysen, Potenziale, Nutzung, pp. 258-270, Vieweg+Teubner GWV Fachverlage, Wiesbaden

Matič, Z. (2007): Sunčevo zračenje na području Republike Hrvatske-Priručnik za energetsko korištenje Sunčevog zračenja (Solar Radiation Handbook of Republic of Croatia), Energetski institut Hrvoje Požar, Zagreb

Messenger, R. A. and Ventre, J. (2010): Photovoltaic Systems Engineering, CRC Press Taylor & Francis Group, Boca Raton, London, New York

Neubarth, J., Kaltschmitt, M., Lippitsch, K., Janczik, S. and Wilk, H. (2009): Photovoltaische Stromerzeugung – Systemtechnische Beschreibung, In: Kaltschmitt, M. and Streicher, W.: Regenerative Energien in Österreich – Grundlagen, Systemtechnik, Umweltaspekte, Kostenanalysen, Potenziale, Nutzung, pp. 206-258, Vieweg+Teubner GWV Fachverlage, Wiesbaden

Quaschning, V. (2009): Regenerative Energiesysteme, Carl Hansen Verlag, München

Scheer, H. (2005): Energieautonomie – Eine neue Politik für erneuerbare Energien, Verlag Kunstmann, München

Scheer, H. (2010): Der energetische Imperativ – 100 Prozent jetzt: Wie der vollständige Wechsel zu erneuerbaren Energien zu realisieren ist, Verlag Kunstmann, München

Scholwin, F., Edelmann, W. and Liebetrau, J. (2009a): Verfahrenstechnik – Biogaserzeugung und -nutzung, In: Kaltschmitt, M., Hartmann, H. and Hofbauer, H.: Energie aus Biomasse – Grundlagen, Techniken und Verfahren, pp. 875 – 909, Springer Verlag, Berlin, Heidelberg, New York

Scholwin, F., Weidele, T. and Gattermann, H. (2009b): Gasaufbereitung und Verwertungsmöglichkeiten, In: Institut für Energetik und Umwelt GmbH, Bundesforschungsanstalt für Landwirtschaft and Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V.: Handreichung Biogasgewinnung und -nutzung, pp. 97 – 116, Fachagentur Nachwachsende Rohstoffe e.V., Gülzow

Seltmann, T. (2000): Fotovoltaik: Strom ohne Ende – Netzgekoppelte Solarstromanlagen optimal bauen und nutzen, Solarpraxis Supernova AG, Berlin

Tschöke, H. (2007): Abgasemissionen von Dieselmotoren – Allgemeine Zusammenhänge, In: Mollenhauer, K. and Tschöke, H.: Handbuch Dieselmotoren, pp. 461-470, Spinger Verlag, Berlin, Heidelberg, New York

Twidell, J. and Weir, T. (2006): Renewable energy resources, Taylor & Francis Group, London, New York

Vinogg, L. and Elstad, I. (2003): Mechanical Equipment, Norwegian University of Science and Technology, Department of Hydraulic and Environmental Engineering, Trondheim

Wagemann, H.-G., and Eschrich, H. (2010): Photovoltaik – Solarstrahlung und Halbleitereigenschaften, Solarzellenkonzepte und Aufgaben, Vieweg+Teubner GWV Fachverlage, Wiesbaden

Wagner, A. (2006): Photovoltaik Engineering – Handbuch für Planung, Entwicklung und Anwendung, Springer Verlag, Berlin, Heidelberg, New York

Zahoransky, R.A. (2007): Energietechnik – Systeme zur Energieumwandlung, Kompaktwissen für Studium und Beruf, Friedr. Vieweg & Sohn Verlag, Wiesbaden

Zahoransky, R.A. (2009): Energietechnik – Systeme zur Energieumwandlung, Kompaktwissen für Studium und Beruf, Vieweg + Teubner/GWV Fachverlage GmbH, Wiesbaden

Expert discussions

Bačan, A. (2010): Engineer at the Department for Renewable Energy Sources and Energy Efficiency, Energy Institute Hrvoje Požar, email-conversation concerning Croatian off-grid PV plants, 02.04.2010

Kubat, D. (2011): Research engineer, Solvis d.o.o., email-conversation concerning efficiency degree of Solvis modules, 25.05.2011

Šimić, Z. (2011): Professor at the University of Zagreb, Faculty of Electrical Engineering and Computing Power Systems Department, email-conversation concerning Croatian PV prices, 11.04.2011

Internet sources

Asel (2011): www.asel.hr – Ostalo – Solarni fotonaponski sustavi – Fotonaponski moduli, http://www.asel.hr/solarni%20monokristalni%20fotonaponski%20paneli.htm, viewed 20.05.2011

Auer, J. (2010): Deutsche Bank Research, PDF „Hydropower in Europe – The Alps, Scandinavia and South-eastern Europe – rich in opportunities", http://www.dbresearch.de/PROD/DBR_INTERNET_DE-PROD/PROD0000000000264559.pdf, viewed 08.07.2011

Baumkunde.de (n.d.): www.baumkunde.de – Baumlisten – Baumarten A-Z – Ölbaum, Olive (Olea europea), http://www.baumkunde.de/Olea_europea/, viewed 08.07.2011

Berger (2011a): www.fritz-berger.de – Elektro – TV und Funk – FTF-Flachbildschirme – TDD 1505, http://www.fritz-berger.de/fbonline/__shop__/product/fritzberger_katalog/TFT-Flachbildschirm1519Reflexion213250/detail.jsf, viewed 20.02.2011

Berger (2011b): www.fritz-berger.de – Elektro – TV und Funk – StereoRadio, http://www.fritz-berger.de/fbonline/__shop__/product/fritzberger_katalog/ StereoRadio2147/detail.jsf, viewed 20.02.2011

Berger (2011c): www.fritz-berger.de – Technik – Wasser – Pumpen – Shurflo Whisperking, http://www.fritz-berger.de/fbonline/__shop__/product/ fritzberger_katalog/ShurfloWhisperking247850/detail.jsf, viewed 20.02.2011

Berger (2011d): www.fritz-berger.de – Technik – Energie – Leuchtmittel – Energiesparlampe DC 12 V, http://www.fritz-berger.de/fbonline/__shop__/ product/fritzberger_katalog/EnergiesparlampeDC12V412540/detail.jsf, viewed 20.02.2011

BHA (2005): British Hydropower Association, PDF „A Guide to UK Mini-Hydro Developments” http://www.british-hydro.org/mini-hydro/download.pdf, viewed 03.07.2011

Bulteel, P. and Capros, P. (2009): PDF „Untying the energy knot of supply security, climate change, economic competitiveness: The Role of Electricity”, http://www.eeinstitute.org/european-review-of-energy-market/EREM% 207%20P.%20Bulteel%20and%20P.%20Capros.pdf, viewed 09.07.2011

BWE (2010): Bundesverband WindEnergie e.V. – PDF „A bis Z – Fakten zur Windenergie – Von der Schaffung neuer Arbeitsplätze bis zur Zukunft der Energieversorgung“, http://www.wind-energie.de/sites/default/files/download/ publication/z-fakten-zur-windenergie/bwe_a-z.pdf, viewed 02.07.2011

Capros, P. (2007): PDF „Eurelectric Project – The Role of Electricity – Modelling Block”, http://www.nuttin.info/SEII/doc/Eurelectric-Capros-2007.pdf, viewed 09.07.2011

Capros, P., Mantzos, L., Tasios, N., De Vita, A. and Kouvaritakis, N. (2010): PDF „EU energy trends to 2030 – Update 2009”, http://ec.europa.eu/energy/observatory/ trends_2030/doc/trends_to_2030_update_2009.pdf, viewed 09.07.2011

Colexon (n.d.): www.colexon.de – Investor Relations – News Center – Newsletterarchiv – Newsletterarchiv 2010 – Colonex NewsBreaker August 2010, http://www.colexon.de/content/de/_newsletter/_2010/_aug/aug_bos.php, viewed 14.07.2011

Croatian Center of RES (2011): Comment concerning Solvis modules at 26.03.2011 on www.alternativeenergy.com, http://alternativeenergycom.ning.com/ profiles/blogs/solarserdarsolvis-fotonaponski#comments, viewed 20.05.2011

DHMZ (n.d. a): Državni hidrometeorološki zavod, Meteorological and Hydrological Service, www.dhmz.htnet.hr – Climate – Croatian wind speed map, http://klima.hr/klima_e.php?id=karta_vjetra_e&param=, viewed 13.04.2011

DZS (2001): Državni zavod za statistiku, Croatian Bureau of Statistics, www.dzs.hr – Released data – Censuses – Census 2011 – Housing units – 1. Dwellings, by occupancy, by town/municipality, http://www.dzs.hr/Eng/censuses/Census2001/ Popis/E03_01_01/E03_01_01.html, viewed 20.05.2011

DZS (2010): Državni zavod za statistiku, Croatian Bureau of Statistics, PDF „Statistical Yearbook 2010“, http://www.dzs.hr/Hrv_Eng/ljetopis/2010/SLJH2010.pdf, viewed 13.04.2011

DZS (2011): Državni zavod za statistiku, Croatian Bureau of Statistics, PDF „Mjesečno statističko izvješće – Monthly Statistical Report – 03/2011“, http://www.dzs.hr/Hrv_Eng/msi/2011/msi-2011_03.pdf, viewed 15.05.2011

EIHP (2010): Energetski institut Hrvoje Požar, Energy institute Hrvoje Požar, PDF „Energija u Hrvatskoj – Godišnji Energetski Pregled – Energy in Croatia – Annual Energy Report” http://www.eihp.hr/hrvatski/projekti/EUH_od_45/Energija09.pdf, viewed 07.07.2011

EIHP (2011): Energetski institut Hrvoje Požar, Energy institute Hrvoje Požar, PDF „Energija u Hrvatskoj od 1945. do 2009. Godine – Energy in Croatia 1945-2009”, http://www.eihp.hr/hrvatski/projekti/EUH_od_45/EnergijaHR45-09.pdf, viewed 07.07.2011

Elgrad (2010): www.elgrad.com – Početna – Webshop – Solarna tehnika – Solarni moduli – Solarni fotonaponski modul 130W/12V, http://elgrad.com/index.php?content=grupe&id=130&proizvod=957, viewed 20.05.2011

Elmag (n.d.): PDF „Stromerzeuger”, http://www.elmag.at/service/prospekte/Gruppe10/katalog-stromerzeuger32seitig.pdf, viewed 04.06.2011

Energy.eu (2011): European Energy Platform, www.energy.eu – Fuel prices – Fuel taxes, http://www.energy.eu/#fueltaxes, viewed 15.07.2011

ENF (2011a): www.enf.cn – Solar Panels – Crystalline – Other Europe, http://www.enf.cn/database/panels-othereu.html, viewed 23.03.2011

ENF (2011b): www.enf.cn – Solar Panels – Thin-Film – Amophous – Producing, http://www.enf.cn/database/panels-amorphous-p.html, viewed 23.03.2011

EPIA (2010): European Photovoltaic Industry Association, PDF „2009 Annual Report”, http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/EPIA_docs/publications/epia/EPIA_Annual_Report_2009.pdf&t=1310656155&hash=ff257c321513198d68cca41c449ac123, viewed 10.07.2011

EPIA (2011a): European Photovoltaic Industry Association, PDF „Solar Generation 6 – Solar photovoltaic electricity empowering the World”, http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/EPIA_docs/documents/SG6/Solar_Generation_6__2011_Full_report_Final.pdf&t=1308356631&hash=8c0f478c2a015c835d63cd3cdcc4d17c, viewed 15.06.2011

EPIA (2011b): European Photovoltaic Industry Association, PDF „Global Market Outlook for Photovoltaics until 2015”, http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/EPIA_docs/publications/epia/EPIA-Global-Market-Outlook-for-Photovoltaics-until-2015.pdf&t=1310656155&hash=f9c62873c3f6348ff460a9716ee9f371, viewed 20.06.2011

ESHA (2004): European Small Hydropower Association, PDF „Guide on How to Develop a Small Hydro Site", http://www.esha.be/fileadmin/esha_files/documents/publications/publications/Part_1_Guide_on_how_to_develop_a_small_hydropower_plant-_Final.pdf and http://www.esha.be/fileadmin/esha_files/documents/publications/publications/Part_2_Guide_on_how_to_develop_a_small_hydropower_plant-_Final-2.pdf, viewed 03.06.2011

European PV Technology Platform (2010): PDF „Photovoltaic Fact Sheets – The Status and Future of the Photovoltaic Market", http://www.eupvplatform.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin%2FDocuments%2FFactSheets%2FEnglish2010%2Ffact_sheet_LB-32-10-253-EN-D.pdf&t=1310853019&hash=55865ca6111644d74b3665bdf612906b, viewed 15.06.2011

Eurostat (2011): epp.eurostat.ec.europa.eu – Statistiken – Suche Datenbank – Datenübersicht – Datenbank nach Themen – Umwelt und Energie – Energie – Energiestatistik – Preise (nrg_price) – Energiestatistik: Gas und Elektrizität Preise – Ab 2007 (nrg_pc) – Elektrizität – Haushaltabnehmer – halbjährliche Preise – Ab 2007 (nrg_pc_204), Date 27.05.2011, http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database, viewed 06.06.2011

Fechner, H., Lugmaier, A., Suna, D., Resch, G., Haas, R. and López-Polo, A. (2007): PDF „Technologie-Roadmap für Photovoltaik in Österreich", http://www.pvaustria.at/upload/269_Roadmap%20Oesterreich%202007.pdf, viewed 10.06.2011

Finanzen.net (2011): www.finanzen.net – Devisen – Dollarkurs – Historische Kurse – 09.05.2011, http://www.finanzen.net/devisen/dollarkurs/historisch, viewed 04.06.2011

Gasoline-Germany (2011): www.gasoline-germany.com – International prices – Croatia, http://gasoline-germany.com/international.phtml?land=106, viewed 05.06.2011

Geothermal-energy.org (2011): www.geothermal-energy.org – Geothermal energy – What is geothermal energy?, http://www.geothermal-energy.org/314,what_is_geothermal_energy.html, viewed 03.07.2011

Gorenje (n.d. a): www.gorenje.hr – Hladnjaci – Prethodni modeli – FH9438W, http://www.gorenje.hr/hladnjaci/prethodni-modeli?c=166996, viewed 20.02.2011

Gorenje (n.d. b): www.gorenje.hr – Hladnjaci – Prethodni modeli – RK4295W, http://www.gorenje.hr/hladnjaci/prethodni-modeli?c=292021, viewed 20.02.2011

GTZ (2009): Deutsche Gesellschaft für Technische Zusammenarbeit – German Technical Cooperation, PDF „International Fuel Prices 2009 – 6th Edition – More than 170 Countries", http://www.gtz.de/de/dokumente/gtz2009-en-ifp-full-version.pdf, viewed 10.06.2011

Haas, R., Stieldorf, K., Wilk, H., López-Polo, A. and Faninger, G. (2002): PDF „Photovoltaik in Gebäuden – IEA Task 7 – Photovoltaic Power Sytems in the Built Environment – Ergebnisse eines Projektes im Rahmen des IEA Implementing-Agreements PV Power Systems“ http://www.nachhaltigwirtschaften.at/nw_pdf/0307_task7.pdf, viewed 17.07.2011

HEP (n.d. a): Hrvatska Elektroprivreda, Croatian national electricity company, www.hep.hr – HEP and Costumers – Electricity Costumers – Customers – Tariff models, http://www.hep.hr/ods/en/customers/Tariff.aspx, viewed 08.06.2011

HEP (n.d. b): Hrvatska Elektroprivreda, Croatian national electricity company, www.hep.hr – HEP and Costumers – Electricity Costumers – Customers – FAQ – Tariffs and tariff models?, http://www.hep.hr/ods/en/customers/faq.aspx, viewed 06.06.2011

HERA (2009): Hrvatska energetska regulatorna agencija, Croatian Energy Regulatory Agency, PDF „Annual Report 2008”, http://www.hera.hr/english/documents/pdf/HERA_Annual_Report_2008.pdf, viewed 06.06.2011

HERA (2010a): Hrvatska energetska regulatorna agencija, Croatian Energy Regulatory Agency, www.hera.hr – Hera – About, http://www.hera.hr/english/html/about.html, viewed 08.06.2011

HERA (2010b): Hrvatska energetska regulatorna agencija, Croatian Energy Regulatory Agency, PDF „Annual Report 2009”, http://www.hera.hr/english/documents/pdf/HERA_Annual_Report_2009.pdf, viewed 06.06.2011

HROTE (n.d.): Hrvatski operator tržišta energije, Croatian Energy Market Operator, www.hrote.hr – HROTE – About us, http://www.hrote.hr/hrote/en/about/default.aspx, viewed 08.06.2011

IEA (2000): International Energy Agency, PDF „Experience curves for energy technology policy” http://www.oecd-ilibrary.org/energy/experience-curves-for-energy-technology-policy_9789264182165-en, viewed 03.02.2011

IEA (2009): International Energy Agency, PDF „World Energy Outlook 2009”, http://www.iea.org/textbase/nppdf/free/2009/weo2009.pdf, viewed 06.05.2011

IEA (2011): International Energy Agency, www.iea.org – By Country – Countries beyond the OECD – Croatia – Statistics for 2008 – Electricity/Heat, http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=HR, viewed 10.07.2011

IEA Bioenergy Task 37 (n.d.): www.sgc.se – FAQ – Biogas and landfill gas, http://www.sgc.se/biogasfaq/#question1, viewed 06.03.2011

IEA PVPS (2010): International Energy Agency Photovoltaic Power System Programme, PDF „Trends in photovoltaic applications – Survey report of selected IEA countries between 1992 and 2009”, http://www.iea-pvps.org/index.php?id=92&eID=dam_frontend_push&docID=432, viewed 15.05.2011

Institute for Applied Ecology (2010): www.gemis.de – Material – Ergebnisse – Ergebnisdaten aus GEMIS 4.6, http://www.gemis.de/files/setup/g46-results_ aug2010daten1.xls, viewed 26.06.2011

Kroatische Zentrale für Tourismus (2011): www.croatia.hr – Reiseziele – Regionen, http://croatia.hr/de-DE/Reiseziele/Regionen, viewed 17.07.2011

Langguth (2011): www.m-langguth.de – Schall – Lärmskala, http://www.m-langguth.de/index.php/schall/laermskala, viewed 07.07.2011

Lindenberger, D., Bartels, M., Seeliger, A., Wissen, R., Hofer, P. and Schlesinger, M. (2006): EWI/Prognos Study, PDF „Auswirkungen höherer Ölpreise auf Energieangebot und -nachfrage – Ölpreisvariante der Energiewirtschaftlichen Referenzprognose 2030“, http://www.ewi.uni-koeln.de/fileadmin/user_upload/ Publikationen/Studien/Politik_und_Gesellschaft/2006/EWI_2006-08_Auswirkungen-hoeherer-Oelpreise.pdf, viewed 08.07.2011

Nacionalni Park Kornati (n.d. a): www.kornati.hr – About the park – What to do, http://www.kornati.hr/eng/sto_raditi.asp, viewed 02.04.2011

Nacionalni Park Kornati (n.d. b): www.kornati.hr – About the park – Natural heritage – Geography, http://www.kornati.hr/eng/pb_geografija.asp, viewed 02.04.2011

Nacionalni Park Kornati (n.d. c): www.kornati.hr – About the park – List of islands, http://www.kornati.hr/eng/popis_otoka.asp, viewed 02.04.2011

Nacionalni Park Kornati (n.d. d): PDF „Kornati National Park and Telašćica Nature Park – UNESCO tentative list”, http://www.kornati.hr/eng/unesco.asp, viewed 01.04.2011

Nacionalni Park Kornati (n.d. e): www.kornati.hr – About the park – Natural heritage – Geology, http://www.kornati.hr/eng/pb_geologija.asp, viewed 02.04.2011

Nacionalni Park Kornati (n.d. f): www.kornati.hr – About the park – Natural heritage – Biology, http://www.kornati.hr/eng/pb_biologija.asp, viewed 02.04.2011

Neupert, U., Euting, T., Kretschmer, T., Notthoff, C., Ruhlig, K. and Weimert, B. (2009): PDF „Energiespeicher – Technische Grundlagen und energiewirtschaftliches Potenzial“, http://publica.fraunhofer.de/eprints/urn:nbn:de:0011-n-897426.pdf, viewed 28.06.2011

Ognjan, D., Robić, S. and Debrecin, N. (2009): PDF „Profitability and the Feasibility of the Photovoltaics in Croatia – Analysis of Technical, Economical and Legal Aspects”, http://www.obnovljivi.com/pdf/PDF_OBNOVLJIVI_COM/2009_IAEE-PROFITABILITY_AND_FEASIBILITY_OF_PHOTOVOLTAICS_IN_CROATIA.pdf, viewed 04.04.2011

Omnibus.hr (2011): www.omnibus.hr – Energija – Cjenik solarne I druge opreme – Cjenik solarne opreme 15.02.2011 – Price list for solar equipment 15.02.2011, http://www.omnibus.hr/cjenik_solarne_opreme.htm, viewed 20.05.2011

Patel, M. (n.d.): PDF „Statistical definitions of non-energy use", http://nws.chem.uu.nl/nenergy/wrks1-603.pdf, viewed 15.07.2011

Purwanto, A., Fermi, F., Fiorello, D., Martino, A., Christidis, P., Schade, B., Soria, A. and Schade, W. (2004): PDF „Assessing the mid and long term impacts of oil price increase on transport demand and fuel consumption in Europe through different scenarios", http://www.eurocities-datta.eu/documents/purwanto_paper.pdf, viewed 08.07.2011

pvresources.com (n.d): www.pvresources.com – Home – Applications – Large-scale photovoltaic power plants ranking 1 - 50, http://www.pvresources.com/ en/top50pv.php, viewed 13.06.2011

pvXchange (2011): PVX Spotmarkt Preisindex Solarmodule cited in www.solarserver.de, Service & Tools – Photovoltaik Preisindex, http://www.solarserver.de/service-tools/photovoltaik-preisindex.html, viewed 17.05.2011

Ragwitz, M., Held, A., Resch, G., Faber, T., Haas, R., Huber, C., Coenraads, R., Voogt, M., Reece, G., Morthorst, P. E., Jensen, S. G., Konstantinaviciute, I. and Heyder B. (2007): PDF „OPTRES – Assessment and optimisation of renewable energy support schemes in the European electricity market – Final report", http://ec.europa.eu/energy/renewables/studies/doc/renewables/2007_02_optres.pdf, viewed 04.04.2011

Rotek (n.d.): www.rotek.at – Onlineshop – Stromgeneratoren – Diesel – 230V 1-Phase – GD4-1-3300-EBDCZ, http://shop.rotek.at/product_info.php?cPath= 126_134_135&products_id=3988&osCsid=kiius95hjd1mim2ugpqj0lg162, viewed 04.06.2011

Rotek (2007): PDF" Benutzerhandbuch GEN034", http://pics.rotek.at/GEN/GEN034/ pdf/gen034_03_Benutzerhandbuch72dpi_de.pdf, viewed 04.06.2011

Rotek (2010): PDF „Produktkatalog 2010-1", http://www.rotek.at/produkte/pdf-aktuell/Kataloge/00_Katalog_Gesamt/Katalog_Gesamt_Rotek_de.pdf, viewed 04.06.2011

Siegfriedt, U. (n.d.): PDF „Was Sie schon immer über Wechselrichter wissen wollten …", http://www.solarzentrum-hamburg.de/download/Wechselrichter _wissen.pdf, viewed 08.07.2011

SMA Solar Technology AG (n.d.): www.solar-is-future.de – FAQ/Glossar – FAQ – Gibt es verschiedene Wirkungsgrade?, http://www.solar-is-future.de/faq-glossar/faq/technik-und-funktionsweise/gibt-es-verschiedene-wirkungsgrade/, viewed 17.04.2011

Solarbuzz (2011a): www.solarbuzz.com – Facts & Figures – Retail Price Environment – Module Prices, http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices, viewed 16.05.2011

Solarbuzz (2011b): www.solarbuzz.com – Facts & Figures – Retail Price Environment – Charge Controller Prices, http://www.solarbuzz.com/facts-and-figures/retail-price-environment/charge-controller-prices, viewed 17.05.2011

Solarbuzz (2011c): www.solarbuzz.com – Facts & Figures – Retail Price Environment – Solar Electricity Prices, http://www.solarbuzz.com/facts-and-figures/retail-price-environment/solar-electricity-prices, viewed 04.06.2011

Solar Europe Industry Initiative (n.d.): PV technology roadmap for commercial technologies, cited in EPIA (2011a): PDF „Solar Generation 6 – Solar photovoltaic electricity empowering the World", http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/EPIA_docs/documents/SG6/Solar_Generation_6__2011_Full_report_Final.pdf&t=1308356631&hash=8c0f478c2a015c835d63cd3cdcc4d17c, viewed 10.07.2011

Solarstromerzeugung.de (n.d.): www.solarstromerzeugung.de – Solarlexikon – W – Wirkungsgrad Solarzellen bzw. Photovoltaikanlage, http://www.solarstromerzeugung.de/wirkungsgrad-photovoltaikanlage-solarzellen.html, viewed 16.04.2011

Solvis (n.d.): PDF „Product range", http://www.solvis.hr/Solvis_product_range.pdf, viewed 05.04.2011

Statkraft (n.d.): www.statkraft.de – Energiequellen – Osmosekraft, http://www.statkraft.de/energiequellen/osmosekraft/, viewed 18.07.2011

Stern, N. (2006): PDF „Stern Review on the Economics of Climate Change", http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/stern_review_report.htm, viewed 18.07.2011

Ugo (2010): www.ugo.hr – Početna – Fotonaponski moduli – Fotonaponski modul 120 W, http://www.ugo.hr/pd/130/pgoid/4/Fotonaponski-modul-120-W-Ugo-d-o-o.wshtml, viewed 20.05.2011

VDE (2008): Verband der Elektrotechnik Elektronik Informationstechnik e.V., www.dke.de – DKE – DKE-IEV Online Wörterbuch – Potentialdifferenz, Nr. 121-11-26, http://www.dke.de/de/Online-Service/DKE-IEV/Seiten/IEV-Woerterbuch.aspx, viewed 17.04.2011

Wollny, M. (2005): PDF „Trends in Decentralized Electrification", http://files.sma.de/dl/1376/Trends-in-decentalised-electrification.pdf, viewed 08.07.2011

World Energy Council (2007): PDF „2007 Survey of Energy Resources", http://www.worldenergy.org/documents/ser2007_final_online_version_1.pdf, viewed 18.07.2011

World Energy Council (2010): PDF „Performance of Generating Plant: New Metrics for Industry in Transition“, http://www.worldenergy.org/publications/2840.asp, viewed 12.06.2011

Yanmar Marine (n.d.): www.yanmarine.com – Find Dealer – Region Europe – Country Croatia, http://www.yanmarmarine.com/index.cfm/go/Distributors/, viewed 10.06.2011

Lecture scripts

Aussenegg, W. (2010): Economic Basics: Valuation and Financing of Energy Projects, MSc Program Renewable Energy in Central and Eastern Europe, module 6

Brösicke, W. (1995): Vorlesungsskript Elektrische Energiewandlern – Photovoltaik Teil 3, FHTW-Berlin, cited in Haselhuhn, R., Hemmerle, C. and Hartmann, U. (2005): Leitfaden Photovotaische Anlagen, DGS, Deutsche Gesellschaft für Sonnenenergie, Landesverband Berlin Brandenburg e.V., Berlin

DHMZ (n.d. b): Državni hidrometeorološki zavod, Meteorological and Hydrological Service, Map" Annual global irradiation on horizontal plane (MWh/m²)" cited in Kulišić, B. (2010a): Potentials of Renewable Energy Production in Croatia – past and future development scenarios, MSc Program Renewable Energy in Central and Eastern Europe, module 7

Drobir, H. (2010): Hydraulic Design of Small Hydroelectric Power Plants, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Fechner, H. (2010): Planning, simulation, costs and financing of PV systems, MSc Program Renewable Energy in Central and Eastern Europe, module 3

Hofbauer, H. (2009a): Fundamentals of Thermal Biomass Utilization, MSc Program Renewable Energy in Central and Eastern Europe, module 2

Hofbauer, H. (2009b): Plant Engineering for Thermal Biomass Utilization, MSc Program Renewable Energy in Central and Eastern Europe, module 2

Krauß, H. (2010): Structural Design of Small Hydroelectric Power Plants, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Krenn, A. (2010a): Wind measurement, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Krenn, A. (2010b): Construction and aerodynamics of wind energy plants; MSc Program Renewable Energy in Central and Eastern Europe, module 4

Krenn, A. (2010c): Technical systems, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Krill, M. (2010): Windpower – Management, Controlling, Skript and lecture notes p. 21, p. 23 and p. 31, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Kulišić, B. (2010a): Potentials of Renewable Energy Production in Croatia – past and future development scenarios, MSc Program Renewable Energy in Central and Eastern Europe, module 7

Kulišić, B. (2010b): Trends and tendencies in electric energy production and utilisation, MSc Program Renewable Energy in Central and Eastern Europe, module 7

Kulišić, B. (2010c): Analysis of strengths and possible future developments, MSc Program Renewable Energy in Central and Eastern Europe, module 7

Lewis, T. (2010): Calculation Examples on Energy Autonomy, MSc Program Renewable Energy in Central and Eastern Europe, module 5

López-Polo, A. (2010): Electricity from the sun: A comparative economic, ecological and technical analysis of Photovoltaic systems, script and lecture note p. 51, MSc Program Renewable Energy in Central and Eastern Europe, module 3

Milics, G. (2010): Geothermal module, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Nakicenovic, N. (2011): Energy Perspectives and the environment – Energy scenarios and their drivers, MSc Program Renewable Energy in Central and Eastern Europe, module 9

Nemac, F. (2010): Country overview Slovenia, script and calculation 'SE Košir Ekonomika', MSc Program Renewable Energy in Central and Eastern Europe, module 7

Panhauser, W. (2010): Mechanical and Electrical Equipment for Small Hydropower Plants, Skript and lecture note p. 36, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Pelikan, B. (2010): Physical principles of hydropower use and environmental problems, Skript and lecture notes p. 2 and 7, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Stanić, Z. (2010): General Legal and Economic Frameworks in Croatia, MSc Program Renewable Energy in Central and Eastern Europe, module 7

Urbatsch, R.-C. (2007): Vorlesungsskript Konventionelle Investitionsentscheidungsrechenverfahren – Kritischer Vergleich unter besonderer Berücksichtigung des vollständigen Finanzplans, Hochschule Mittweida (FH)

Valdimarsson, P. (2010): Technical units for geothermal utilization – Introduction, MSc Program Renewable Energy in Central and Eastern Europe, module 4

Weiss, W. (2010): Solar thermal systems and components, script and lecture note p. 19, MSc Program Renewable Energy in Central and Eastern Europe, module 3

Weißensteiner, L. (2009): Economics of electricity generation from renewable energy sources – Costs of electricity generation from renewable energy sources Solar thermal systems and components, MSc Program Renewable Energy in Central and Eastern Europe, module 1

Wellinger, A. (2009): Anerobic digestion, appendix, MSc Program Renewable Energy in Central and Eastern Europe, module 2

Legislative texts

Ministarstvo Financija (2009): Ministry of Finance – Tax Administration, Compilation of current tax legislation, PDF „The Croatian Tax System", http://www.porezna-uprava.hr/contentData/pdf%20datoteke/brošure/HPS_2011_ENG.pdf, viewed 15.07.2011

Narodne novine (2006a): Croatian official gazette, Zakon o tržištu nafte i naftnih derivata – Law about the trade with cruide oil and petroleum products, Narodne novine Nr. 57, 24.05.2006, http://narodne-novine.nn.hr/clanci/sluzbeni/127095.html, viewed 15.07.2011

Narodne novine (2006b): Croatian official gazette, Pravilnik o utvrđivanju cijena naftnih derivata – Decree for the assessment of petroleum products, Narodne novine Nr. 68, 19.06.2006, http://narodne-novine.nn.hr/clanci/sluzbeni/ 2006_06_68_1635.html, viewed 15.07.2011

Programs

Fugawi Global Navigator (n.d.): Version 3, www.fugawi.com

Google Maps (2011): www.maps.google.de

Meteonorm (2008): Version 6.0.1.2, www.meteonorm.com

Retscreen (2010): Version 4, www.retscreen.net

Satel Light (2011): The European Database of Daylight and Solar Radiation, www.satel-light.com

Annex A – Site visit Kornat

15.03.2011

Site visit Vrulje

43° 48’ N, 15° 18’ E (Fugawi n.d.)

15 houses and 3 restaurants

The majority of the houses are inhabited constantly during the summer and partly in the winter (the local residents normally work and live on the mainland near Murter)

3 inhabitants per house on average

No room heating

Only 3 houses have solar thermal collectors, no warm water preparation in the rest

Diesel generators at each house with 5 to 15 kW nominal power and electric outlet of 12 and 230 V

Some houses have a small number of PV modules (1 to 3 modules), connected with a battery system with approx. 100 to 200 Ah, to supply the 12 V-consumers (light bulbs, water pump, etc.)

Restaurants run the diesel generator approx. 10 hours a day during summer time

Cookers, stoves, refrigerators and freezers are operated with gas

No washing machines or air condition

Electric devices: Light bulbs, radio, television, water pump

16.03.2011

Site visit Strižnja

43° 49’ N, 15° 17’ E (Fugawi, n.d.)

3 houses and 2 restaurants

4 inhabitants per house on average, on the summer weekends up to 10 persons in the houses

20 seats for guests in the restaurants

No room heating, no warm water preparation

Diesel generators with 5 to 6 kW at the restaurants, operation time during summer between 8 to 10 hours per day.

Average diesel consumption approx. 3 litres per hour

The houses have smaller generators with 2 to 3 kW nominal power.

2 houses with additional PV modules (1 to 3 modules), connected with a battery system (180 Ah)

All generators have a 12 and 220 V electric outlet to supply the different consumers.

Refrigerator with 150 litres and freezer with 50 litres storage capacity are operated with 20 kg gas for 20 days.

Cookers and stoves are heated with gas or wood (from the olive groves)

No washing machines or air condition

Electric devices: Light bulbs, radio, television, water pump

Annex B – Consumption and specifications of electrical devices

Table 27: Energy consumers within the reference house
Source: Author's personal research results (2011) based on Gorenje (n.d. a and n.d. b) and Berger (2011a to 2010d)

Energy consumers						
Device	Producer (Source)	Article	Nominal power (W)	Number of devices	Sum nominal power (W)	Voltage
Freezer	Gorenje (n.d. a)	FH9438W	30.50	1	30.50	230
Refrigerator with integrated freezer	Gorenje (n.d. b)	RK4295W	37.80	1	37.80	230
TV	Berger (2011a)	TDD-1505	40.00	1	40.00	230
Radio	Berger (2011b)	Stereoradio	20.00	1	20.00	230
Water pump	Berger (2011c)	Shurflo Whisperking	60.00	1	60.00	12
Light bulbs	Berger (2011d)	412540	11.00	15	165.00	12
Light bulbs	Berger (2011d)	412550	15.00	5	75.00	12
Energy consumption					**428.30**	

Table 28: Annual energy consumption of the reference location
Source: Author’s personal research results (2011)

Annual energy consumption					January				February				March			
Device	Nominal power (W)	Amount	Sum nominal power (W)	Voltage (V)	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.
Freezer	30.50	1	30.50	230	0	0	0	0	0	0	0	0	0	0	0	0
Refrigerator with integrated freezer	37.80	1	37.80	230	24	0.91	31	28.21	24	0.91	28	25.48	24	0.91	31	28.21
TV	40.00	1	40.00	230	1	0.04	31	1.24	1	0.04	28	1.12	1	0.04	31	1.24
Radio	20.00	1	20.00	230	3	0.06	31	1.86	3	0.06	28	1.68	3	0.06	31	1.86
Water pump	60.00	1	60.00	12	1	0.06	31	1.86	1	0.06	28	1.68	1	0.06	31	1.86
Light bulbs	11.00	15	165.00	12	2	0.33	31	10.23	2	0.33	28	9.24	2	0.33	31	10.23
Light bulbs	15.00	5	75.00	12	3	0.23	31	7.13	3	0.23	28	6.44	3	0.23	31	7.13
Energy consumption			428.30			1.63		50.53		1.63		45.64		1.63		50.53

Device	April				Mai				June				July			
	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.
Freezer	0	0	0	0	24	0.73	15	10.95	24	0.73	30	21.90	24	0.73	31	22.63
Refrigerator with integrated freezer	24	0.91	30	27.30	24	0.91	31	28.21	24	0.91	30	27.30	24	0.91	31	28.21
TV	1	0.04	30	1.20	2	0.08	31	2.48	4	0.16	30	4.80	4	0.16	31	4.96
Radio	3	0.06	30	1.80	3	0.06	31	1.86	3	0.06	30	1.80	3	0.06	31	1.86
Water pump	1	0.06	30	1.80	2	0.12	31	3.72	3	0.18	30	5.40	4	0.24	31	7.44
Light bulbs	2	0.33	30	9.90	2	0.33	31	10.23	2	0.33	30	9.90	2	0.33	31	10.23
Light bulbs	3	0.23	30	6.90	2	0.15	31	4.65	1	0.08	30	2.40	1	0.08	31	2.48
Energy consumption		1.63		48.90		2.38		62.10		2.45		73.50		2.51		77.81

Device	August				September				October				November			
	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.	h/ d	kWh/ d	d/ mon.	kWh/ mon.
Freezer	24	0.73	31	22.63	24	0.73	30	21.90	0	0	0	0	0	0	0	0
Refrigerator with integrated freezer	24	0.91	31	28.21	24	0.91	30	27.30	24	0.91	31	28.21	24	0.91	30	27.30
TV	4	0.16	31	4.96	3	0.12	30	3.60	2	0.08	31	2.48	1	0.04	30	1.20
Radio	3	0.06	31	1.86	3	0.06	30	1.80	3	0.06	31	1.86	3	0.06	30	1.80
Water pump	4	0.24	31	7.44	3	0.18	30	5.40	3	0.18	31	5.58	1	0.06	30	1.80
Light bulbs	2	0.33	31	10.23	2	0.33	30	9.90	2	0.33	31	10.23	2	0.33	30	9.90
Light bulbs	1	0.08	31	2.48	2	0.15	30	4.50	2	0.15	31	4.65	3	0.23	30	6.90
Energy consumption		2.51		77.81		2.48		74.40		1.71		53.01		1.63		48.90

Device	December				Sum
	h/ d	kWh/ d	d/ mon.	kWh/ mon.	
Freezer	0	0	0	0	
Refrigerator with integrated freezer	24	0.91	31	28.21	
TV	1	0.04	31	1.24	
Radio	3	0.06	31	1.86	
Water pump	1	0.06	31	1.86	
Light bulbs	2	0.33	31	10.23	
Light bulbs	3	0.23	31	7.13	
Energy consumption		1.63		50.53	713.66 kWh

Annex C – Sun radiation and further calculation data

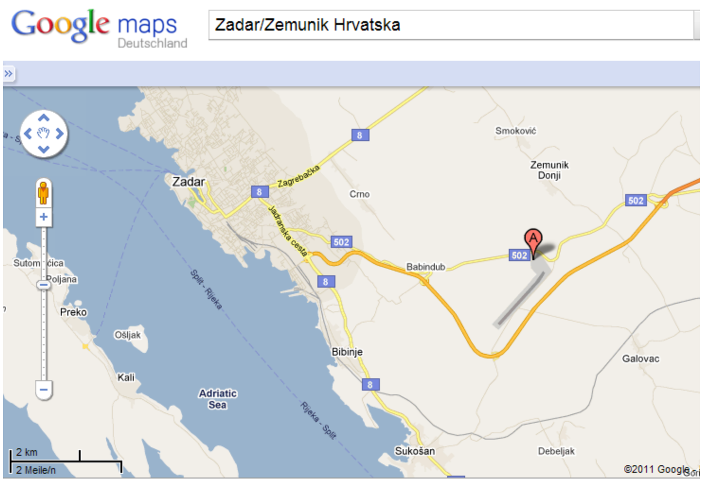

Figure 15: Location Zadar/Zemunik
Source: Google (2011)

Table 29: Radiation data of Zadar/Zemunik
Source: Retscreen (2010)

RETScreen

Land - Region		Kroatien	
Provinz/Bundesland		n/a	
Standort für die Klimadaten		Zadar/Zemunik	
Breite	°N	44,1	Quelle
Länge	°E	15,4	
Höhe	m	84	Boden
Auslegungstemperatur Heizungsbedarf	°C	-3,1	Boden
Auslegungstemperatur Kühlungsbedarf	°C	31,8	Boden
Amplitude der Bodentemperatur	°C	19,7	NASA

	Lufttemperatur	Relative Luftfeuchte	Tägliche Solareinstrahlung - horizontal	Atmosphärischer Druck	Windgeschwindigkeit	Bodentemperatur	Monatliche Heiz-gradtage	Kühlungs-Gradtage
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	4,8	76,8%	1,30	98,1	2,4	0,8	409	0
Feb	5,5	75,1%	2,14	97,9	2,5	2,2	350	0
Mär	8,2	71,8%	3,27	97,8	3,0	7,1	304	0
Apr	12,5	72,7%	4,06	97,5	3,0	11,8	165	75
Mai	16,8	73,0%	5,29	97,6	2,4	17,5	37	211
Jun	20,5	68,9%	6,01	97,7	2,3	21,7	0	315
Jul	23,9	63,1%	6,21	97,7	2,4	24,7	0	431
Aug	23,4	65,7%	5,39	97,7	2,3	24,1	0	415
Sep	19,4	74,2%	3,88	97,8	2,3	18,5	0	282
Okt	14,8	79,1%	2,35	98,0	2,3	13,0	99	149
Nov	9,5	79,4%	1,33	97,9	2,6	6,4	255	0
Dez	6,6	79,2%	1,05	98,0	2,5	1,7	353	0
Jährlich	13,9	73,2%	3,53	97,8	2,5	12,5	1.973	1.878
Quelle	Boden	Boden	NASA	NASA	Boden	NASA	Boden	Boden
			Gemessen bei	m	10	0		

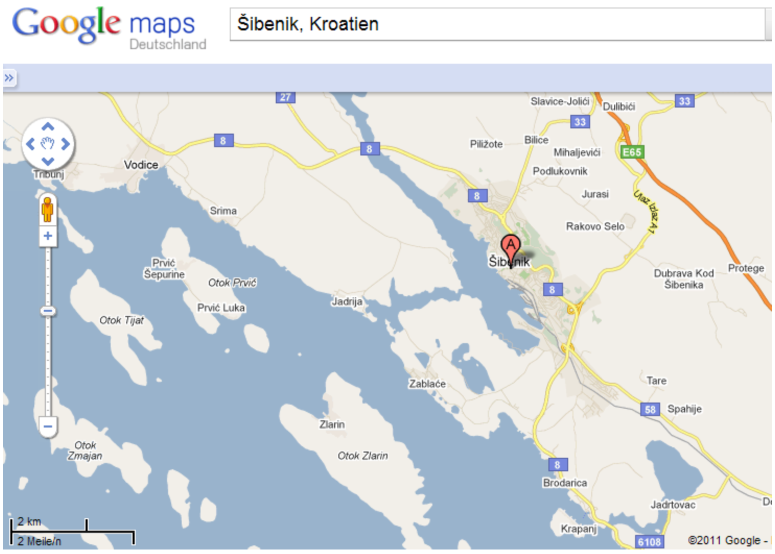

Figure 16: Location Šibenik
Source: Google (2011)

Table 30: Radiation data of Šibenik
Source: Retscreen (2010)

RETScreen

Land - Region		Kroatien	
Provinz/Bundesland		n/a	
Standort für die Klimadaten		Šibenik	
Breite	°N	43,7	
Länge	°E	15,9	Quelle
Höhe	m	223	NASA
Auslegungstemperatur Heizungsbedarf	°C	0,1	NASA
Auslegungstemperatur Kühlungsbedarf	°C	28,0	NASA
Amplitude der Bodentemperatur	°C	14,9	NASA

	Lufttemperatur	Relative Luftfeuchte	Tägliche Solareinstrahlung - horizontal	Atmosphärischer Druck	Windgeschwindigkeit	Bodentemperatur	Monatliche Heiz-gradtage	Kühlungs-Gradtage
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	5,2	71,6%	1,68	99,3	3,5	5,4	397	0
Feb	5,8	68,9%	2,64	99,1	3,6	6,2	341	0
Mär	9,1	65,7%	4,00	99,0	3,3	9,5	276	0
Apr	12,5	64,9%	5,28	98,7	3,2	13,1	166	74
Mai	17,3	62,3%	6,59	98,9	2,7	17,9	22	226
Jun	21,0	58,5%	7,35	98,9	2,6	21,9	0	331
Jul	23,7	54,8%	7,51	98,9	2,5	24,6	0	426
Aug	23,8	56,5%	6,51	98,9	2,6	24,6	0	426
Sep	19,7	61,1%	4,87	99,0	2,7	20,2	0	290
Okt	15,6	67,2%	3,09	99,2	3,2	15,7	73	175
Nov	10,3	72,4%	1,75	99,1	3,5	10,3	232	8
Dez	6,4	72,6%	1,38	99,2	3,6	6,5	360	0
Jährlich	14,3	64,7%	4,40	99,0	3,1	14,7	1.867	1.956
Quelle	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
			Gemessen bei	m	10	0		

Table 31: Srednja dnevna ozračenost prema jugu nagnute plohe [kWh/m²]
Source: Matič (2007)

Mjesec	Nagib 0°			
	Ukupno	Raspršeno	Izravno	Odbijeno
Siječanj	1.62	0.82	0.80	0.00
Veljača	2.61	1.12	1.49	0.00
Ožujak	3.92	1.64	2.28	0.00
Travanj	5.21	2.09	3.12	0.00
Svibanj	6.22	2.49	3.73	0.00
Lipanj	6.90	2.54	4.36	0.00
Srpanj	6.90	2.39	4.51	0.00
Kolovoz	5.92	2.18	3.74	0.00
Rujan	4.68	1.68	3.00	0.00
Listopad	3.33	1.26	2.07	0.00
Studeni	1.89	0.91	0.98	0.00
Prosinac	1.40	0.73	0.67	0.00
Prosječno	4.22	1.66	2.57	0.00
∑ [MWh/m²]	1.54	0.60	0.94	0.00

Table 32: Mean daily sun radiation on a south orientated surface [kWh/m²]
Source: Matič (2007) translation by the author (2011)

Month	Inclination 0°			
	Total global radiation	Diffuse radiation	Direct radiation	Reflected light
January	1.62	0.82	0.80	0.00
February	2.61	1.12	1.49	0.00
March	3.92	1.64	2.28	0.00
April	5.21	2.09	3.12	0.00
May	6.22	2.49	3.73	0.00
June	6.90	2.54	4.36	0.00
July	6.90	2.39	4.51	0.00
August	5.92	2.18	3.74	0.00
September	4.68	1.68	3.00	0.00
October	3.33	1.26	2.07	0.00
November	1.89	0.91	0.98	0.00
December	1.40	0.73	0.67	0.00
Average	4.22	1.66	2.57	0.00
∑ [MWh/m²]	1.54	0.60	0.94	0.00

Table 33: Global horizontal irradiance (Wh/m²)
Source: Satel Light (2011)

S@tel-Light Lat : 43°48'N Lon : 15°18'E Alt : 10 m
From : Sunrise To : Sunset Using : Clock Time Years : 1996 to 2000
Parameter : Global Horizontal Irradiance
Information : Monthly Mean of daily sums (Wh/m2)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Mean	1660	2632	3919	4766	6525	7323	7092	6308	4570	2827	1631	1346	4226

Table 34: Radiation data for Vrulje at an inclination of 0°
Source: Meteonorm (2008)

Standortname = Vrulje

Geogr. Breite [°] = 43,484, Geogr. Länge [°] = 15,183, Höhe [m] = 10, Klimaregion = IV, 1

Albedo = fix

Strahlungsmodell = Standard (Stunde); Temperaturmodell = Standard (Stunde)

Modell für geneigte Flächen = Perez

Temperatur: Neue Periode = 1996-2005

Strahlung: Neue Periode = 1981-2000

Gh: Nur 4 Station(en) für Interpolation

SD: Nur 3 Station(en) für Interpolation

RD: Nur 2 Station(en) für Interpolation

Monat	H_Gh	H_Dh	H_Bn	Ta
Jan	51	22	86	7,2
Feb	70	31	94	7,5
Mar	120	49	136	10,7
Apr	152	67	140	13,9
Mai	196	73	193	19,6
Jun	206	77	190	23,8
Jul	214	76	208	25,9
Aug	186	75	174	25,8
Sep	141	45	171	20,6
Okt	105	38	140	16,9
Nov	58	27	85	12,4
Dez	48	22	86	8,4
Jahr	1542	600	1704	16,1

-
Legende:
H_Gh: Strahlungss. der Globalstrahlung horiz.
H_Dh: Strahlungssumme der Diffusstrahlung horiz.
H_Bn: Strahlungssumme der Direktnormalstrahlung
Ta: Lufttemperatur
Strahlung in [kWh/m]
Temperatur in [C]

Table 35: Radiation data for Vrulje at an inclination of 15°
Source: Meteonorm (2008)

Azimut = 0°, Neigung = 15°

Monat	H_Gh	H_Dh	H_Gk	H_Dk	H_Bn	Ta
Jan	51	22	72	25	86	7,2
Feb	70	31	90	34	94	7,5
Mar	120	49	142	54	136	10,7
Apr	152	67	166	71	140	13,9
Mai	196	73	203	77	193	19,6
Jun	206	77	210	80	190	23,8
Jul	214	76	221	80	208	25,9
Aug	186	75	199	80	174	25,8
Sep	141	45	163	50	171	20,6
Okt	105	38	131	43	140	16,9
Nov	58	27	78	31	85	12,4
Dez	48	22	70	26	86	8,4
Jahr	1542	600	1745	652	1704	16,1

-
Legende:
H_Gh: Strahlungss. der Globalstrahlung horiz.
H_Dh: Strahlungssumme der Diffusstrahlung horiz.
H_Gk: Strahlungssumme der Globalstrahlung geneigt
H_Dk: Strahlungssumme der Diffusstr. geneigt
H_Bn: Strahlungssumme der Direktnormalstrahlung
Ta: Lufttemperatur
Strahlung in [kWh/m]
Temperatur in [C]

Table 36: Radiation data for Vrulje at an inclination of 30°
Source: Meteonorm (2008)

Azimut = 0°, Neigung = 30°

Monat	H_Gh	H_Dh	H_Gk	H_Dk	H_Bn	Ta
Jan	51	22	89	28	86	7,2
Feb	70	31	106	38	94	7,5
Mar	120	49	158	59	136	10,7
Apr	152	67	173	74	140	13,9
Mai	196	73	203	80	193	19,6
Jun	206	77	206	83	190	23,8
Jul	214	76	218	84	208	25,9
Aug	186	75	204	85	174	25,8
Sep	141	45	177	55	171	20,6
Okt	105	38	152	49	140	16,9
Nov	58	27	94	34	85	12,4
Dez	48	22	88	30	86	8,4
Jahr	1542	600	1867	700	1704	16,1

-
Legende:
H_Gh: Strahlungss. der Globalstrahlung horiz.
H_Dh: Strahlungssumme der Diffusstrahlung horiz.
H_Gk: Strahlungssumme der Globalstrahlung geneigt
H_Dk: Strahlungssumme der Diffusstr. geneigt
H_Bn: Strahlungssumme der Direktnormalstrahlung
Ta: Lufttemperatur
Strahlung in [kWh/m]
Temperatur in [C]

Table 37: Radiation data for Vrulje at an inclination of 45°
Source: Meteonorm (2008)

Azimut = 0°, Neigung = 45°

Monat	H_Gh	H_Dh	H_Gk	H_Dk	H_Bn	Ta
Jan	51	22	101	31	86	7,2
Feb	70	31	117	41	94	7,5
Mar	120	49	166	63	136	10,7
Apr	152	67	173	77	140	13,9
Mai	196	73	194	83	193	19,6
Jun	206	77	193	85	190	23,8
Jul	214	76	206	87	208	25,9
Aug	186	75	200	88	174	25,8
Sep	141	45	183	60	171	20,6
Okt	105	38	165	53	140	16,9
Nov	58	27	106	38	85	12,4
Dez	48	22	102	33	86	8,4
Jahr	1542	600	1905	740	1704	16,1

-
Legende:
H_Gh: Strahlungss. der Globalstrahlung horiz.
H_Dh: Strahlungssumme der Diffusstrahlung horiz.
H_Gk: Strahlungssumme der Globalstrahlung geneigt
H_Dk: Strahlungssumme der Diffusstr. geneigt
H_Bn: Strahlungssumme der Direktnormalstrahlung
Ta: Lufttemperatur
Strahlung in [kWh/m]
Temperatur in [C]

Table 38: Radiation data for Vrulje at an inclination of 60°
Source: Meteonorm (2008)

Azimut = 0°, Neigung = 60°

Monat	H_Gh	H_Dh	H_Gk	H_Dk	H_Bn	Ta
Jan	51	22	108	33	86	7,2
Feb	70	31	121	43	94	7,5
Mar	120	49	166	66	136	10,7
Apr	152	67	165	78	140	13,9
Mai	196	73	177	86	193	19,6
Jun	206	77	172	87	190	23,8
Jul	214	76	186	90	208	25,9
Aug	186	75	187	90	174	25,8
Sep	141	45	179	64	171	20,6
Okt	105	38	169	56	140	16,9
Nov	58	27	112	40	85	12,4
Dez	48	22	110	36	86	8,4
Jahr	1542	600	1853	769	1704	16,1

-
Legende:
H_Gh: Strahlungss. der Globalstrahlung horiz.
H_Dh: Strahlungssumme der Diffusstrahlung horiz.
H_Gk: Strahlungssumme der Globalstrahlung geneigt
H_Dk: Strahlungssumme der Diffusstr. geneigt
H_Bn: Strahlungssumme der Direktnormalstrahlung
Ta: Lufttemperatur
Strahlung in [kWh/m]
Temperatur in [C]

Table 39: Heat coefficients
Source: Häberlin (2010)

Temperatureinfluss klein:
Freifeldaufstellung kristalliner Module oder bei Modulen aus amorphem Silizium

	Jan	Feb	März	Apr	Mai	Juni	Juli	Aug	Sep	Okt	Nov	Dez	Jahr
Kloten	1.06	1.05	1.02	1.00	0.97	0.96	0.94	0.94	0.97	1.01	1.04	1.06	0.98
Davos	1.05	1.04	1.02	1.01	0.99	0.98	0.96	0.97	0.99	1.01	1.04	1.05	1.00
Locarno	1.03	1.03	1.01	1.00	0.98	0.95	0.93	0.93	0.96	0.99	1.02	1.03	0.98
Potsdam	1.07	1.06	1.03	1.00	0.97	0.95	0.94	0.95	0.98	1.01	1.04	1.06	0.98
Giessen	1.06	1.05	1.03	1.00	0.97	0.95	0.95	0.96	0.99	1.01	1.04	1.06	0.98
München	1.06	1.05	1.02	1.00	0.97	0.95	0.94	0.95	0.97	1.00	1.04	1.05	0.98
Marseille	1.00	1.00	0.98	0.96	0.94	0.92	0.90	0.91	0.94	0.96	0.99	1.00	0.95
Sevilla	0.98	0.97	0.95	0.95	0.92	0.90	0.88	0.89	0.91	0.93	0.97	0.98	0.93
Kairo	0.96	0.94	0.93	0.91	0.89	0.88	0.88	0.88	0.89	0.90	0.93	0.95	0.91

Temperatureinfluss mittel:
Aufdachmontage mit Hinterlüftung oder Fassadenintegration kristalliner Module

	Jan	Feb	März	Apr	Mai	Juni	Juli	Aug	Sep	Okt	Nov	Dez	Jahr
Kloten	1.05	1.03	1.01	0.98	0.95	0.93	0.91	0.92	0.95	0.99	1.04	1.05	0.96
Davos	1.03	1.02	1.00	0.98	0.97	0.96	0.94	0.95	0.97	0.98	1.02	1.03	0.98
Locarno	1.02	1.02	0.99	0.98	0.96	0.93	0.90	0.91	0.94	0.98	1.01	1.02	0.96
Potsdam	1.06	1.05	1.02	0.98	0.94	0.93	0.92	0.93	0.96	1.00	1.04	1.06	0.96
Giessen	1.06	1.04	1.01	0.98	0.94	0.93	0.92	0.93	0.97	1.00	1.04	1.06	0.96
München	1.05	1.03	1.01	0.98	0.94	0.92	0.92	0.93	0.95	0.99	1.02	1.04	0.96
Marseille	0.98	0.98	0.95	0.93	0.91	0.89	0.87	0.88	0.91	0.93	0.97	0.98	0.92
Sevilla	0.95	0.95	0.93	0.92	0.89	0.87	0.85	0.85	0.88	0.91	0.95	0.96	0.90
Kairo	0.93	0.92	0.90	0.88	0.86	0.84	0.84	0.84	0.86	0.87	0.90	0.93	0.88

Temperatureinfluss hoch:
Kristalline Module ohne Hinterlüftung in Dächern integriert

	Jan	Feb	März	Apr	Mai	Juni	Juli	Aug	Sep	Okt	Nov	Dez	Jahr
Kloten	1.04	1.02	0.99	0.96	0.93	0.91	0.89	0.90	0.93	0.98	1.03	1.04	0.94
Davos	1.00	0.99	0.97	0.96	0.94	0.93	0.91	0.92	0.94	0.96	1.00	1.01	0.96
Locarno	1.00	1.00	0.97	0.97	0.94	0.90	0.87	0.88	0.92	0.96	0.99	1.00	0.94
Potsdam	1.05	1.04	1.00	0.96	0.92	0.90	0.90	0.91	0.94	0.98	1.03	1.05	0.94
Giessen	1.05	1.03	1.00	0.96	0.92	0.91	0.90	0.91	0.96	0.99	1.03	1.05	0.95
München	1.03	1.01	0.99	0.95	0.92	0.90	0.89	0.90	0.93	0.97	1.01	1.03	0.94
Marseille	0.96	0.96	0.93	0.91	0.88	0.86	0.84	0.85	0.89	0.91	0.95	0.96	0.90
Sevilla	0.93	0.92	0.90	0.89	0.86	0.84	0.81	0.82	0.86	0.88	0.93	0.94	0.87
Kairo	0.90	0.89	0.87	0.84	0.82	0.81	0.81	0.81	0.83	0.84	0.87	0.90	0.84

Annex D – PV plant and battery dimensioning

Table 40: Features of Solvis poly-crystalline modules
Source: Solvis (n.d.)

POLYCRYSTALLINE MODULES		
THERMAL CHARACTERISTICS		
Nominal operating cell temperature (NOCT)	[°C]	48,2 ± 2
Temperature coefficient of P_{MPP}	[%/K]	-0,41
Temperature coefficient of I_{SC}	[%/K]	0,05
Temperature coefficient of U_{OC}	[%/K]	-0,29
DESCRIPTION		
Solar cells		Polycrystalline Si, 156 x 156 mm
Cell encapsulation		Ethylene vinyl acetate (EVA)
Front		Tempered solar glass, 4 mm
Back		Composite polyester film
Frame		Anodized aluminum frame with twin-wall profile and drainage holes
Junction box		Tyco SOLARLOK with 3 bypass diodes, IP65
Cable and connectors		Solar cable 4 mm², length 1000 mm, Tyco SOLARLOK connectors
OPERATING CONDITIONS		
Temperature range	[°C]	-40 to +85
Maximum system voltage [V]	[V]	1000
Maximum surface load capacity		Tested up to 5400 Pa (Snow load test)
Resistance against hail		Maximum diameter of 25 mm with impact speed of 23 m/s
WARRANTIES AND CERTIFICATIONS		
Product warranty		5 years
Performance warranty		Power output of 90 % for 12 years and 80 % for 25 years
Product quality certificate		EN IEC 61215:2004
Product quality certificate		The Microcogeneration Scheme Certificate
Product safety certificate		EN IEC 61730-2:2007
Quality management certificate		ISO 9001:2008
Environmental management certificate		ISO 14001:2009
Occupational health and safety management certificate		OHSAS 18001:2007

Table 41: Solvis module performance under STC
Source: Solvis (n.d.)

SV 36

Performance under standard test conditions (1000 W/m², 25 °C, AM 1.5 according to EN 60904-3)

ELECTRICAL DATA		SV 36-120	SV 36-125	SV 36-130	SV 36-135	SV 36-140
Peak power	P_{MPP} [W]	120	125	130	135	140
Peak power tolerance	[%]			± 3		
Short circuit current	I_{SC} [A]	7,69	7,85	8,01	8,16	8,31
Open circuit voltage	U_{OC} [V]	20,8	21,1	21,5	21,8	22,1
Rated current	I_{MPP} [A]	7,19	7,34	7,49	7,63	7,77
Rated voltage	U_{MPP} [V]	16,7	17	17,4	17,7	18
Current and voltage tolerance	[%]			± 10		
MECHANICAL DATA						
Dimensions (H x W x D)	[mm]			1030 x 998 x 35		
Weight	[kg]			14		
WARRANTIES AND CERTIFICATIONS						
Product warranty				5 years		
Performance warranty				Power output of 90 % for 12 years and 80 % for 25 years		
Product quality certificate				EN IEC 61215:2004		
Product quality certificate				The Microcogeneration Scheme Certificate		
Product safety certificate				EN IEC 61730-2:2007		
Quality management certificate				ISO 9001:2008		
Environmental management certificate				ISO 14001:2009		
Occupational health and safety management certificate				OHSAS 18001:2007		

Table 42: PV plant configuration
Source: Author's personal research results (2011)

Energy yield						January				February			
							kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Sun radiation		F1			kWh/(m²*d)	1.65				2.50			
Inclination		F2	45°		Factor	1.98				1.67			
Heat coefficiant		F3	roof-mounted		Factor	0.98				0.98			
Module efficiency		F4	12.20 %		Factor	0.12				0.12			
Cable losses		L1	6.00 %		Factor	0.94				0.94			
Conversion losses		L2	10.00 %		Factor	0.90				0.90			
Mismatch losses		L3	10.00 %		Factor	0.90				0.90			
Real energy yield		F1xF2xF3xF4xL1xL2xL3			kWh/(m²*d)		0.30	31	9.30		0.38	28	10.64

Dimensioning													
Module surface of Solvis SV-36-125		1.03	m²			January				February			
Amount of modules			pieces				5.28	pieces			4.16	pieces	
Max. amount of modules		5.28	pieces										
Reserve		13.64	%										
Final amount of Modules		6.00	pieces										
Nominal power per module		125.00	Wp										
Plant dimension		750.00	Wp										

Power production						January				February			
							kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Energy production		750.00	Wp		kWh/d		1.85	31	57.35		2.35	28	65.80
Daily surplus energy production	0.22	kWh min.	1.46	kWh max.	kWh/d		0.22				0.72		
Daily surplus energy production	13.50	% min.	89.57	% max.	%		13.50				44.17		

Energy yield		March				April				Mai			
			kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Sun radiation	kWh/(m²*d)	3.87				5.07				6.32			
Inclination	Factor	1.38				1.14				0.99			
Heat coefficiant	Factor	0.95				0.93				0.91			
Module efficiency	Factor	0.12				0.12				0.12			
Cable losses	Factor	0.94				0.94				0.94			
Conversion losses	Factor	0.90				0.90				0.90			
Mismatch losses	Factor	0.90				0.90				0.90			
Real energy yield	kWh/(m²*d)		0.47	31	14.57		0.50	30	15.00		0.53	31	16.43

Dimensioning	March				April				Mai			
Amount of modules		3.37	pieces			3.17	pieces			4.36	pieces	

Power production		March				April				Mai			
			kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Energy production	kWh/d		2.90	31	89.90		3.09	30	92.70		3.28	31	101.68
Daily surplus energy production	kWh/d		1.27				1.46				0.90		
Daily surplus energy production	%		77.91				89.57				37.82		

Energy yield		June				July				August			
			kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Sun radiation	kWh/(m²*d)	6.87				6.90				6.00			
Inclination	Factor	0.94				0.96				1.08			
Heat coefficiant	Factor	0.89				0.87				0.88			
Module efficiency	Factor	0.12				0.12				0.12			
Cable losses	Factor	0.94				0.94				0.94			
Conversion losses	Factor	0.90				0.90				0.90			
Mismatch losses	Factor	0.90				0.90				0.90			
Real energy yield	kWh/(m²*d)		0.53	30	15.90		0.54	31	16.74		0.53	31	16.43

Dimensioning	June				July				August			
Amount of modules		4.49	pieces			4.51	pieces			4.60	pieces	

Power production		June				July				August			
			kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Energy production	kWh/d		3.28	30	98.40		3.34	31	103.54		3.28	31	101.68
Daily surplus energy production	kWh/d		0.83				0.83				0.77		
Daily surplus energy production	%		33.88				33.07				30.68		

Energy yield		September				October				November			
			kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Sun radiation	kWh/(m²*d)	4.70				3.39				1.93			
Inclination	Factor	1.30				1.57				1.83			
Heat coefficiant	Factor	0.91				0.93				0.97			
Module efficiency	Factor	0.12				0.12				0.12			
Cable losses	Factor	0.94				0.94				0.94			
Conversion losses	Factor	0.90				0.90				0.90			
Mismatch losses	Factor	0.90				0.90				0.90			
Real energy yield	kWh/(m²*d)		0.52	30	15.60		0.46	31	14.26		0.32	30	9.60

Dimensioning		September				October				November			
Amount of modules			4.63	pieces			3.61	pieces			4.95	pieces	

Power production		September				October				November			
			kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.		kWh/ d	d/ mon.	kWh/ mon.
Energy production	kWh/d		3.21	30	96.30		2.84	31	88.04		1.98	30	59.40
Daily surplus energy production	kWh/d		0.73				1.13				0.35		
Daily surplus energy production	%		29.44				66.08				21.47		

Energy yield		December				Radiation
			kWh/ d	d/ mon.	kWh/ mon.	
Sun radiation	kWh/(m²*d)	1.55				**1,547.00 kWh/m²**
Inclination	Factor	2.13				
Heat coefficiant	Factor	0.98				
Module efficiency	Factor	0.12				
Cable losses	Factor	0.94				
Conversion losses	Factor	0.90				
Mismatch losses	Factor	0.90				
Real energy yield	kWh/(m²*d)		0.30	31	9.30	**163.77 kWh/m²**

Dimensioning		December			
Amount of modules			5.28	pieces	

Power production		December				Energy yield
			kWh/ d	d/ mon.	kWh/ mon.	
Energy production	kWh/d		1,85	31	57.35	**1,012.14 kWh/p.a.**
Daily surplus energy production	kWh/d		0,22			
Daily surplus energy production	%		13.50			

Table 43: Battery dimensioning
Source: Author’s personal research results (2011)

Battery dimensioning				January			February			March			April		
Discharge rate		50	%												
Voltage	Un	12	V												
Autonomy factor winter	Fw	4.00	days	Fw			Fw			Fw					
Autonomy factor summer	Fs	2.50	days										Fs		
Daily energy consumption					1.63	Wh/d		1.63	Wh/d		1.63	Wh/d		1.63	Wh/d
Battery capacity	Cn	=(2 x Wh/d x F)/Un			1,086.67	Ah		1,086.67	Ah		1,086.67	Ah		679.17	Ah

Battery dimensioning	Mai			June			July			August			September		
Discharge rate															
Voltage															
Autonomy factor winter															
Autonomy factor summer	Fs			Fs			Fs			Fs			Fs		
Daily energy consumption		2.38	Wh/d		2.45	Wh/d		2.51	Wh/d		2.51	Wh/d		2.48	Wh/d
Battery capacity		991.67	Ah		1,020.83	Ah		1,045.83	Ah		1,045.83	Ah		1,033.33	Ah

Battery dimensioning	October			November			December		
Discharge rate									
Voltage									
Autonomy factor winter	Fw			Fw			Fw		
Autonomy factor summer									
Daily energy consumption		1.71	Wh/d		1.63	Wh/d		1.63	Wh/d
Battery capacity		1,140.00	Ah	Fw	1,086.67	Ah	Fw	1,086.67	Ah

Max. battery capacity	1,140.00	Ah
Reserve	110.00	Ah
Battery-Dimensioning	1,250.00	Ah

Annex E – Diesel generator dimensioning

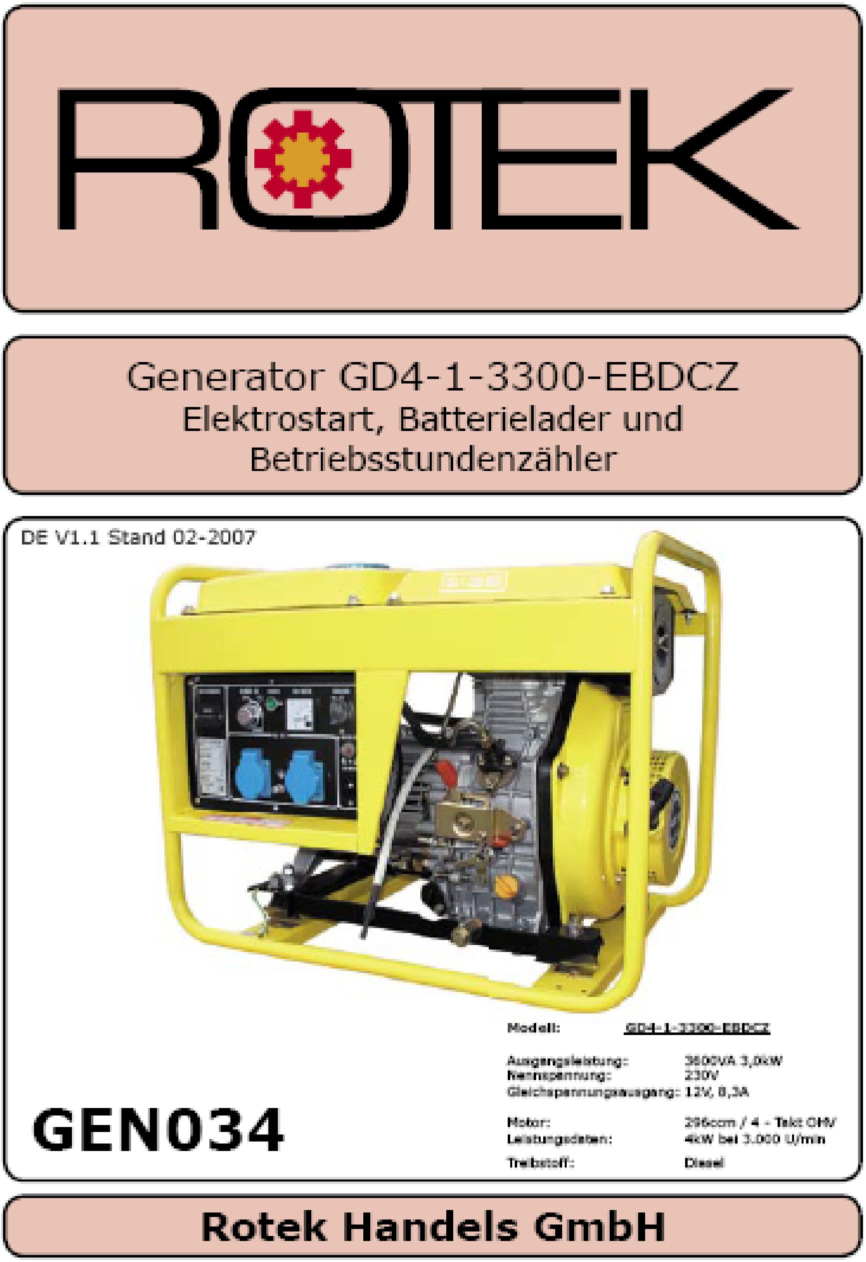

Figure 17: Description diesel generator
Source: Rotek (2007)

Table 44: Specification diesel generator
Source: Rotek (2007)

Spezifikation

Stromerzeuger für Heim- und Gewerbebedarf, Synchrongenerator 3600VA, 230V, 50Hz in Industriequalität mit Betriebsstundenzähler

Technische Daten - Generator	
Type	Einphasiger Synchrongenerator
Frequenz	50 Hz
Ausgangsleistung*	3600 VA, Spitzenleistung 3,3 kW / 230V, Dauerleistung 3.0 kW / 230V
Nennspannung	230V, Motorschutzschalter 13A
Gleichspannungsausgang	12V, 7 A
Erregung	Selbsterregung mit Permanentmagneten

Technische Daten - Motor	
Type	Dieselmotor, Einzylinder 4-Takt, Direkteinspritzer, Luftgekühlt
Hubraum	296 ccm
Maximale Leistung [Treibstoffverbrauch]	5.44PS (4.0kW) @ 3000 min-1 [1.2 Liter/h]
Startsystem	Elektrostarter, VRLA Startbatterie enthalten
Treibstoff	Diesel
Schmieröl	0W30 od. 10W40 API CF/ CH-4/CI-4 vollsynthetisch 1.35 Liter - vorgefüllt, Ölstand kontrollieren !

Technische Daten - Gesamtsystem	
Tankkapazität	11.5 Liter
Betriebsdauer mit Tankfüllung	9 Stunden
Lautstärke	96 dbA @ 4 Meter
Abmessungen (BxTxH)	680 x 460 x 540 mm
Gewicht	83 kg

Table 45: Suggested diesel generator service intervals
Source: Rotek (2007)

Serviceintervalle

Arbeiten	Täglich	nach den ersten 20 Stunden (Einlaufen)	alle 3 Monate oder 100 Stunden	Alle 6 Monate oder 300 Stunden	Jährlich oder 1000 Stunden
Schaltpanel, Anschlüsse	◇				
Treibstoff prüfen/auffüllen	◇				
Tanksieb	◇		◇ reinigen		
Ölstand kontrollieren, ergänzen	◇				
auf Ölverlust kontrollieren	◇				
Sitz aller Schrauben prüfen	◇	• Zylinderkopfschrauben nachziehen		• Zylinderkopfschrauben nachziehen	
Ölwechsel		◇	◇		
Luftfilter	in staubiger Umgebung öfter prüfen / reinigen / ersetzen			◇ ersetzen	
Treibstofffilter				◇ reinigen	◇ ersetzen
Treibstoffleitung				• wenn notwendig, ersetzen	
Ventile einstellen		•		•	
Kompression, Kolbenringe prüfen/ersetzen					•
Ventile einschleifen					•

◇ ..... durch Benutzer durchzuführen
• ..... spezielles Werkzeug bzw. Fachkenntnis notwendig (durch Fachhändler durchzuführen)

Table 46: Assumed diesel generator service intervals with time and cost estimations
Source: Author's personal research results (2011) based on Rotek (2007)

Intervals / **Time exposure (min)** / **Service works**	Daily		Every 180 hours		Every 360 hours		Twice a year		Yearly		Annual time exposure (min)	Annual costs (€)	Assumptions
	Each time	p.a.	Each time	p.a.	Each time	p.a.	Each time	p.a.	Each time	p.a.			
Check switchboard connection	5	1,825									1,825		
Check fuel, Refilling													
Check tank sieve													
Check oil, Refilling													
Check oil leakage													
Check cylinder head screw													
Cleaning tank sieve			15	150							150		
Change of oil			15	150							150	135	10 x 1.35 l oil, 10 € per litre oil
Fixing cyliner head screw					30	150					150		
Change of air filter					15	75					75	100	20 € per filter
Cleaning of fuel filter					15	75					75		
Adjusting of valves					30	150					150		
Change of fuel lines							60	120			120	100	50 € per line set
Change of fuel filter									15	30	30	20	20 € per filter
Check compression and piston rings, replacement of piston rings, seating of valves									Professionist necessary		0	150	Work time, travel time, repair parts
											2,725	**505**	

Annex F – Financial analyses

Table 47: PV NPV calculation
Source: Author's personal research results (2011) based on Wellinger (2009)

PV NPV calculation (€)		Annual price increase / Discount rate	Periods										
			0	1	2	3	4	5	6	7	8	9	10
Investment			-4,263.61						-1,400.00				
Avoided costs			3,000.00										
Revenues		2.00 %		85.86	87.39	89.14	90.92	92.74	94.59	96.48	98.41	100.38	102.39
Costs	**Insurance**	1.00 %		-13.49	-13.62	-13.76	-13.90	-14.04	-14.18	-14.32	-14.46	-14.60	-14.75
	Rapairs	1.00 %		-6.75	-6.82	-6.89	-6.96	-7.03	-7.10	-7.17	-7.24	-7.31	-7.38
Cash flows				65.44	66.95	68.49	70.06	71.67	-1,326.69	74.99	76.71	78.47	80.26
Discounted cash flows		7.70 %		60.76	57.72	54.83	52.07	49.46	-850.11	44.62	42.38	40.25	38.22
Sum			-1,263.61	-1,202.85	-1,145.13	-1,090.30	-1,038.23	-988.77	-1,838.88	-1,794.26	-1,751.88	-1,711.63	-1,693.41

PV NPV calculation (€)		Annual price increase / Discount rate	Periods									
			11	12	13	14	15	16	17	18	19	20
Investment				-1,400.00						-1,400.00		
Avoided costs												
Revenues		2.00 %	104.44	106.53	108.66	110.83	113.05	115.31	117.62	119.97	122.37	124.82
Costs	**Insurance**	1.00 %	-14.90	5	-15.20	-15.35	-15.50	-15.66	-15.82	-15.98	-16.14	-16.30
	Rapairs	1.00 %	-7.45	-7.52	-7.60	-7.68	-7.76	-7.84	-7.92	-8.00	-8.08	-8.16
Cash flows			82.09	-1,316.04	85.86	87.80	89.79	91.81	93.88	-1,304.01	98.15	100.36
Discounted cash flows		7.70 %	36.30	-540.36	32.73	31.08	29.51	28.02	26.60	-343.08	23.98	22.76
Sum			-1,637.11	-2,177.47	-2,144.74	-2,113.66	-2,084.15	-2,056.13	-2,029.53	-2,372.61	-2,348.63	**-2,325.87**

Table 48: Diesel NPV calculation
Source: Author's personal research results (2011) based on Wellinger (2009)

PV NPV calculation		Annual price increase / Discount rate	Periods										
			0	1	2	3	4	5	6	7	8	9	10
Investment			-1,396.65		-50.00		-175.44		-1,086.00		-175.44		-50.00
Avoided costs			3,000.00										
Revenues		2.00 %		85.68	87.39	89.14	90.92	92.74	94.59	96.48	98.41	100.38	102.39
Costs	O&M	1.00 %		-505.00	-510.05	-515.15	-520.30	-525.50	-530.76	-536.07	-541.43	-546.84	-552.31
	Fuel	2.00 %		-3,700.00	-3,774.00	-3,849.48	-3,926.47	-4,005.00	-4,085.10	-4,166.80	-4,250.14	-4,335.14	-4,421.84
Cash flows				-4,119.32	-4,246.66	-4,275.49	-4,531.29	-4,437.76	-5,607.27	-4,606.39	-4,868.60	-4,781.60	-4,921.76
Discounted cash flows		7.70 %		-3,824.81	-3,661.14	-3,422.46	-3,367.90	-3,062.56	-3,593.00	-2,740.63	-2,689.54	-2,452.63	-2,344.03
Sum			-1,603.35	-2,221.46	-5,882.60	-9,305.06	-12,672.96	-15,735.52	-19,328.52	-22,069.15	-24,758.69	-27,211.32	-29,555.35

PV NPV calculation		Annual price increase / Discount rate	Periods									
			11	12	13	14	15	16	17	18	19	20
Investment				-1,211.44		-50.00		-175.44		-1,086.00		-175.44
Avoided costs												
Revenues		2.00 %	104.44	106.53	108.66	110.83	113.05	115.31	117.62	119.97	122.37	124.82
Costs	O&M	1.00 %	-557.83	-563.41	-569.04	-574.73	-580.48	-586.28	-592.14	-598.06	-604.04	-610.08
	Fuel	2.00 %	-4,510.28	-4,600.49	-4,692.50	-4,786.35	-4,882.08	-4,979.72	-5,079.31	-5,180.90	-5,284.52	-5,390.21
Cash flows			-4,963.67	-6,268.81	-5,152.88	-5,300.25	-5,349.51	-5,626.13	-5,553.83	-6,744.99	-5,766.19	-6,050.91
Discounted cash flows		7.70 %	-2,194.98	-2,573.93	-1,964.47	-1,876.19	-1,758.24	-1,716.95	-1,573.71	-1,774.59	-1,408.61	-1,372.48
Sum			-31,750.33	-34,324.26	-36,288.73	-38,164.92	-39,923.16	-41,640.11	-43,213.82	-44,988.41	-46,397.02	**-47,769.50**

Table 49: PV sensitivity analysis
Source: Author's personal research results (2011)

PV sensitivity analysis						
Percentual change of parameters	**Electricity price**		**Initial investment costs**		**Calc. interest rate**	
	€/kWh	**NPV**	**€**	**NPV**	**%**	**NPV**
-50%	0.06	-2,824.09	-2,131.81	-194.07	3.85	-2,883.33
-40%	0.07	-2,724.41	-2,558.17	-620.43	4.62	-2,748.18
-30%	0.08	-2,624.79	-2,984.53	-1,046.79	5.39	-2,626.26
-20%	0.10	-2,525.25	-3,410.89	-1,473.15	6.16	-2,516.10
-10%	0.11	-2,425.51	-3,837.25	-1,899.51	6.93	-2,416.34
0%	0.12	-2,325.87	-4,263.61	-2,325.87	7.70	-2,325.87
10%	0.13	-2,226.23	-4,689.97	-2,752.23	8.47	-2,243.65
20%	0.14	-2,126.49	-5,116.33	-3,178.59	9.24	-2,168.82
30%	0.16	-2,026.88	-5,542.69	-3,604.95	10.01	-2,100.61
40%	0.17	-1,927.11	-5,969.05	-4,031.31	10.78	-2,038.33
50%	0.18	-1,827.67	-6,395.42	-4,457.68	11.55	-1,981.32

Table 50: Diesel sensitivity analysis
Source: Author's personal research results (2011)

Diesel sensitivity analysis						
Percentual change of parameters	**Electricity price**		**Diesel price**		**Calc. interest rate**	
	€/kWh	**NPV**	**€/l**	**NPV**	**%**	**NPV**
-50%	0.06	-48,267.73	0,63	-26,252.47	3.85	-67,709.85
-40%	0.07	-48,168.06	0,75	-30,555.94	4.62	-62,875.59
-30%	0.08	-48,068.45	0,88	-34,859.37	5.39	-58,515.76
-20%	0.10	-47,968.90	1,00	-39,162.64	6.16	-54,575.68
-10%	0.11	-47,869.17	1,13	-43,466.03	6.93	-51,007.51
0%	0.12	-47,769.50	1,25	-47,769.50	7.70	-47,769.50
10%	0.13	-47,669.88	1,38	-52,072.87	8.47	-44,825.24
20%	0.14	-47,570.12	1,50	-56,376.28	9.24	-42,142.67
30%	0.16	-47,470.54	1,63	-60,679.62	10.01	-39,693.75
40%	0.17	-47,370.77	1,75	-64,983.00	10.78	-37,453.71
50%	0.18	-47,271.30	1,88	-69,286.26	11.55	-35,400.93

Annex G – Scenarios

Table 51: Comparison of scenario calculations
Source: Author's personal research results (2011)

Year	Electricity price (€/kWh)			PV LRMC (€/kWh)			Diesel LRMC (€/kWh)		
	2008-2010	Scenario A	Scenario B	2008-2011	Scenario A	Scenario B	2008-2011	Scenario A	Scenario B
		+ 1 % p.a.	+ 2.5 % p.a.		-5 % p.a., same efficiency	-5 % p.a., incr. efficiency		+ 2.5 % p.a.	+ 4.0 % p.a.
2008	0.10	0.10	0.10	0.69	0.69	0.69	1.04	1.04	1.04
2009	0.12	0.12	0.12	0.67	0.67	0.67	0.86	0.86	0.86
2010	0.12	0.12	0.12	0.66	0.66	0.66	0.98	0.98	0.98
2011		0.12	0.12	0.65	0.65	0.65	1.08	1.08	1.08
2012		0.12	0.12		0.63	0.62		1.10	1.12
2013		0.12	0.12		0.62	0.60		1.13	1.15
2014		0.12	0.13		0.61	0.57		1.15	1.19
2015		0.12	0.13		0.60	0.55		1.17	1.23
2016		0.12	0.13		0.59	0.53		1.20	1.27
2017		0.12	0.14		0.58	0.51		1.22	1.31
2018		0.12	0.14		0.57	0.49		1.24	1.35
2019		0.13	0.14		0.56	0.48		1.27	1.40
2020		0.13	0.15		0.55	0.46		1.30	1.45
2021		0.13	0.15		0.54	0.44		1.32	1.49
2022		0.13	0.16		0.53	0.43		1.35	1.54
2023		0.13	0.16		0.52	0.42		1.38	1.60
2024		0.13	0.16		0.52	0.40		1.41	1.65
2025		0.13	0.17		0.51	0.39		1.44	1.71
2026		0.14	0.17		0.50	0.38		1.47	1.77
2027		0.14	0.18		0.50	0.37		1.50	1.83
2028		0.14	0.18		0.49	0.36		1.53	1.89
2029		0.14	0.18		0.49	0.35		1.56	1.96
2030		0.14	0.19		0.48	0.34		1.60	2.03