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Stratified Energy Access in Niger

By Jürgen Raach

RAACH SOLAR

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RAACH SOLAR
Im Stellwinkel 1
88451 Dettingen Iller
Germany
Juergen.raach@t-online.de

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Executive Summary

Shortly after the financial crises in 2008 and 2009, overcapacities in solar module production led worldwide to a sharp decline of raw material and photovoltaic module prices. Solar module manufacturers sold their modules even under production costs to stay competitive in the market which finally lead to several bankruptcies and financial difficulties of Chinese, European and American manufacturers. In 2012 to 2014, we have seen a consolidation of the production capacities and the worldwide PV market still continues to grow. The feed-in tariffs will fade out because photovoltaic power generation has reached in 2013 grid parity. Production costs of photovoltaic grid connected power generation have dropped to 14 € cents/kWh (19 US cents/kWh) in the northern hemisphere and to 8 €cents/kWh (10 US cents/kWh) in the African sun belt.

The feasibility study on stratified energy access by photovoltaic power in Niger covers two major subjects. Starting point is the insight analysis of the current situation in Niger for photovoltaic systems, recommendations for the best practice photovoltaic technologies to be applied in the context of Niger and the creation of a financial model which allows to scale up the use of photovoltaic power for rural electrification.

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ABBREVIATIONS

ANPER	Agence Nigérienne de Promotion de l' Electrification en milieu Rural
ARE	Alliance for Rural Electrification
ASER	Agence Sénégalaise d'Electrification Rurale
CER	Cellule de l'Électrification Rurale
CISG	UN convention on Contracts for the International Sale of Goods and services
CNES	Centre National d'Énergie Solaire
EDF	European Development Fund
EnDev	Energising Development Program
EEG	Erneuerbare Energien Gesetz (Renewable Energy Act)
HH	Houeshold (hh)
IEA	International Energy Agency
KWH	Kilo Watt Hour
KWP	Kilo Watt Peak (solar module)
MEP	Ministère d'Énergie et de Pétrole
MFI	Micro Finance Institutions
NGO	Non Gouvernmental Organization
NIGELEC	Société d'Électricité
PASE	Programme d'Accès aux Services Energétiques pour la Commune rurale de Safo
PPP	Private Public Partnership
PRASE	Programme national de Référence d'Accès aux Services Energétiques modernes
PV	photovoltaic; photovoltaics
RESCO	Renewable Energy Service COmpany
SE4ALL	Solar Energy For All
SHS	Solar Home System
SNV	Société Néerlandaise de Développement

1. PHOTOVOLTAICS IN NIGER

1.1 Niger as part of the global solar initiatives

1.1.1 Sustainable Energy For All (SE4ALL)

The “Solar for All Intitiative” was founded by David Green, vice president of Ashoka International and by Peter W. Heller, CEO of Canopus Foundation in the year 2008, when prices for solar modules started to drop significantly and new LED light technologies were introduced to the market.

This initiative was picked up by the United Nations and led to a broader definition of renewable energies in the “Sustainable Energy for All Initiative”, abbreviated by “SE4ALL” and launched by the UN secretary-general in the year 2011. The three major targets are[1]:

1. Ensure universal access to modern energy services (=universal energy access).
2. Double the global rate of improvement in energy efficiency (=energy efficiency).
3. Double the share of renewable energy in the global energy mix (=renewable energy).

The UN general assembly declared the next decade from 2014-2024 as the “Decade for Sustainable Energy for All”. More than 75 countries worldwide have committed to follow the SE4ALL objectives, including the Government of Niger. The partners who help to implement the initiative are well known organizations such as the African Development Bank (AfDB), UNEP and the Worldbank.

1.1.2 Lighting Africa

“Lighting Africa” is a joint IFC and Worldbank program which sets out minimum technical quality standards for modern off grid lighting products powered by photovoltaic modules. The program was launched in the year 2007 and targets 600 million people in Africa with no access to electricity.

1.1.3 European Union

After the military coup in Niger in 2010, the EU partially suspended the cooperation with Niger and resumed activities in June 2011, but is mainly focused on governance, migration and security. The EU has dedicated important financial grants of €483 million to Niger under the 10th European development Fund (EDF) from 2008 to 2013. In November 2013, the EU allocated €542 million of new grants to Niger for the period of 2014 to 2020. Four sectors will profit from this financial support: food security, the social sectors, road infrastructure and domestic security and stability. Some photovoltaic infrastructure projects like solar pumping systems will be cofounded by these grants.

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[1] Source: www.se4all.org

In the past the European Union's largest support for photovoltaic systems went into photovoltaic pumping systems to the Burkina based CILSS organization. In the first phase from 1990 to 1998 of the Regional Solar Program (PRS1), 66 solar pumping systems were installed, in the second phase (PRS2) from 2001 to 2009 almost 100 solar pumping systems were installed, whereas approximately half of them were rehabilitated from phase 1.

1.1.4 Bilateral initiatives

The African Development Bank has several ongoing projects in Niger, especially in the agricultural sector to improve food security. The AEPA project started in 2012 and will help to improve the water and drinking water supply in the rural areas by drilling 300 new boreholes including the delivery of hand pumps and solar pumps, coordinated by the national Ministère en Charge de l'Eau.

SNV is at present the sole organization in Niger is currently working on a project to bring more than 1.2 million solar powered pico lighting systems into the market. The project starts in 2014 and will go beyond 2019.

The French Development Aid Agency AFD (Agence Francaise de Développement) is a minority shareholder (0.45%) of the state electricity company NIGELEC (Société Nigérienne d'Électricité). There is no special activity for photovoltaic systems in Niger[2]. AFD works on two electrification projects (2013-2017) in Niamey (€30 million) and rural areas (€11 million) which is mainly extension of the existing public grid. Another important focus of the AFD in Niger is water sanitation and water supply of the rural population. Several solar powered pumping systems have been funded by the infrastructure projects to achieve the access to drinking water for the rural population at a rate of 80% until the year 2015.

The US African Development Foundation (USADF) established by the US congress has several ongoing projects in agriculture and community development in Niger, but there is no special support program for renewable energies.

USAID carries out a program "Power Africa" which was officially started by the US president Barack Obama in June 2013 during a visit to South Africa. The US government has committed more than US$7 billion funds and loan guarantees to this project. In West Africa, the initiative already leverages projects in Liberia, Ghana and Nigeria. In Niger, USAID focuses at present on addressing malnutrition and food insecurity as well as strengthening the country's democratic institutions[3].

The GIZ carried out in the 80's and 90's several solar pumping projects, but has no special solar energy related project ongoing in Niger[4]. GIZ major focus in Niger is food security (project PROSAR) and food storage (project POMAP) which is in line with the governments food autonomy program "I3N" (= les nigeriens nourissent les nigeriens).

However the GIZ played a major role in setting up the Energising Development (EnDev) Program which started in the year 2005 as a result of partnership between the Netherlands and Germany.

[2] Interview with Mr. Habibou Boubacar (AFD) in Niamey, 29.11.2013
[3] http://www.usaid.gov/niger
[4] Interview with Mr. Berdelmann (GIZ) in Niamey, 02.12.2013

Additional donors, Norway, UK, Australia and Switzerland joined the partnership. The target of the program is to supply 14 million people with access to sustainable energy. In West Africa, the program is implemented in Mali, Burkina Faso, Ghana, Benin, Liberia and Senegal, but not in Niger.

1.2 Photovoltaic market analysis in Niger

1.2.1 PV market potential

The solar irradiation conditions in Niger are most favorable for the use of photovoltaic power. Niamey has double the solar irradiation over a year compared to Paris or New York. If a 1kWp solar array produces 1000 to 1100kWh per year in Paris, it produces between 2000 to 2200kWh per year in Niamey. Diagram 1 shows the direct comparison of the average monthly solar irradiation between Niamey and Paris. The data shows the monthly average amount of the total solar radiation incident on a horizontal surface at the surface of the earth for a given month, averaged for that month over the 22-year period (Jul 1983 - Jun 2005)[5].

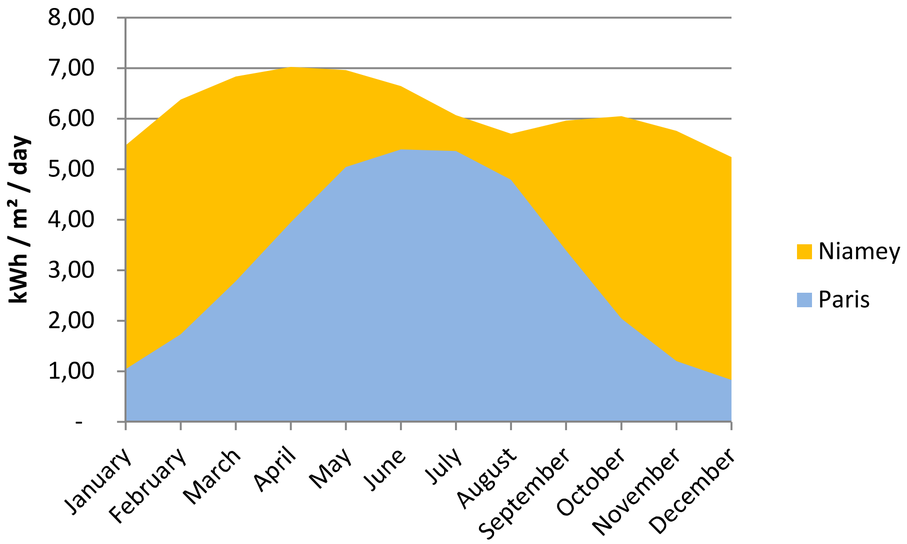

Figure 1: solar irradiation comparison between Niamey (Niger) and Paris (France)
Source: RAACH SOLAR, data from https://eosweb.larc.nasa.gov

According to the IRENA, the electricity use per capita in Niger is 43kWh / year (in 2010). At a current population (in 2012) of 17.1 million people the estimated total electricity consumption is 735 million kWh. To produce this energy without storage by a large photovoltaic power plant or small distributed PV power plants, a theoretical photovoltaic capacity of **367 MWp** would be necessary. The necessary photovoltaic surface would cover an area of 2.936.km² or a square area of 54km to 54km compared of the total national surface of 1.267.000km². Photovoltaic power could cover easily 100% of Niger's

[5] Nasa, USA

current electricity demand. At current photovoltaic power plant prices between 1.000 and 1.500€ /kWp, the total market volume can be estimated at **€550 million**.

This theoretical market potential and market size will constantly increase over the next years by the increasing population, increasing living standard (kWh / capita), increasing industrialization and economic growth. Niger has one of the highest population growths worldwide with more than 3% per year. The AfDB puts Niger's GDP growth in 2012 at 13.1% in real terms and estimates that growth will continue in 2013 at a rate of 5.5%, more than the expected growth of the population.

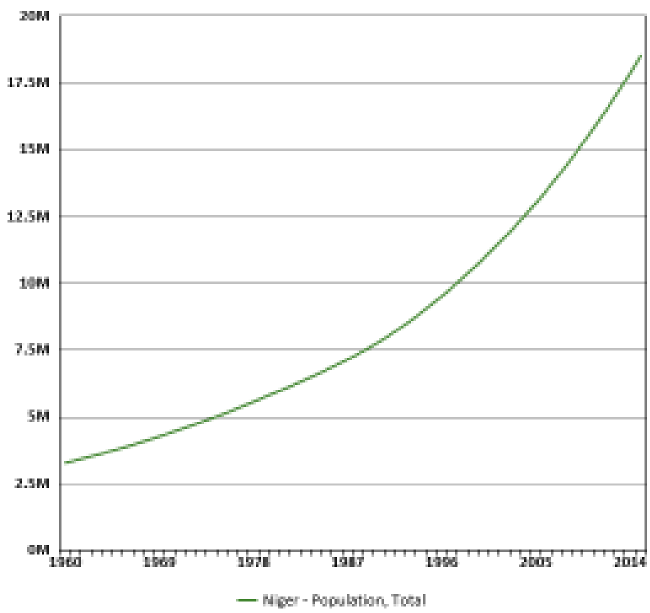

Figure 2: population growth in Niger according to the AfDB
Source: http://niger.opendataforafrica.org

Niger's GNP comes mainly from agriculture (40%) and the export of uranium (20%). The discovery of 328 million barrels oil and 10 billion cubic meters of gas[6], will further boost the economy in the next decade. At the same time there is a strong threat to the use of more renewable energies in Niger by these discoveries through a strong orientation towards fossil fuels and further pollution problems.

[6] Source: Niger Energy Services (NES), www.nigerenergies.com

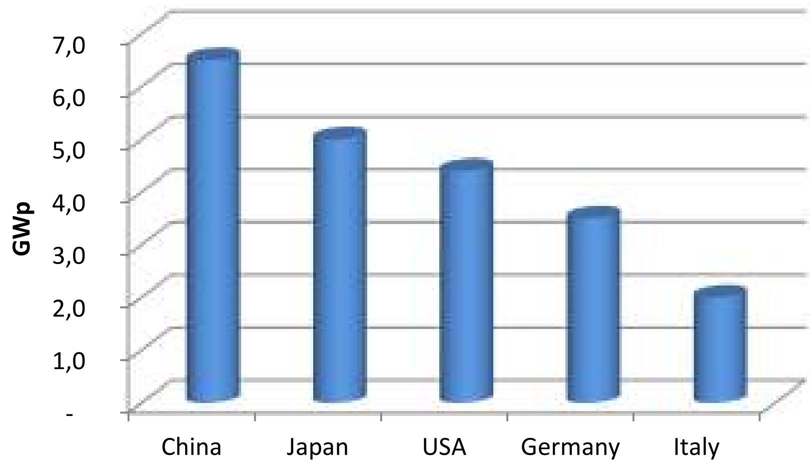

Figure 3: top 5 photovoltaic market demands
(not production capacities) in the world in 2013, preliminary estimations
Source: RAACH SOLAR, data from NPD Solarbuzz, PV-magazine, VDE-Nachrichten

Photovoltaic power can provide a cheap and clean solution to the electricity supply situation in Niger. Compared to an annual PV market size in the top 5 PV markets in the world of more than 21.000MWp (21GWp) in the year 2013, the mission to orientate Niger towards photovoltaic power is more than feasible. The photovoltaic world market is said to grow to 45-55GWp in the year 2014 in spite of the financial difficulties of many manufacturers[7].

1.2.2 Actual PV market size

It is very hard to get official data on the real market size of photovoltaic systems in Niger. The national solar energy centre (CNES = Centre National d'Énergie Solaire) made an inventory in 2007 over the accumulated installed PV capacity in Niger and presented the result of 1.115kWp. Mr. Moumouni Habi from the CNES announced that the inventory will be soon repeated and updated[8]. The CNES role is the promotion of solar energy by research & development, training, studies, networking with university, creation of public awareness and after sales service issues.

[7] NPD-Solarbuzz, USA
[8] Interview with Mr. Habi (CNES) in Niamey, 28.11.2013

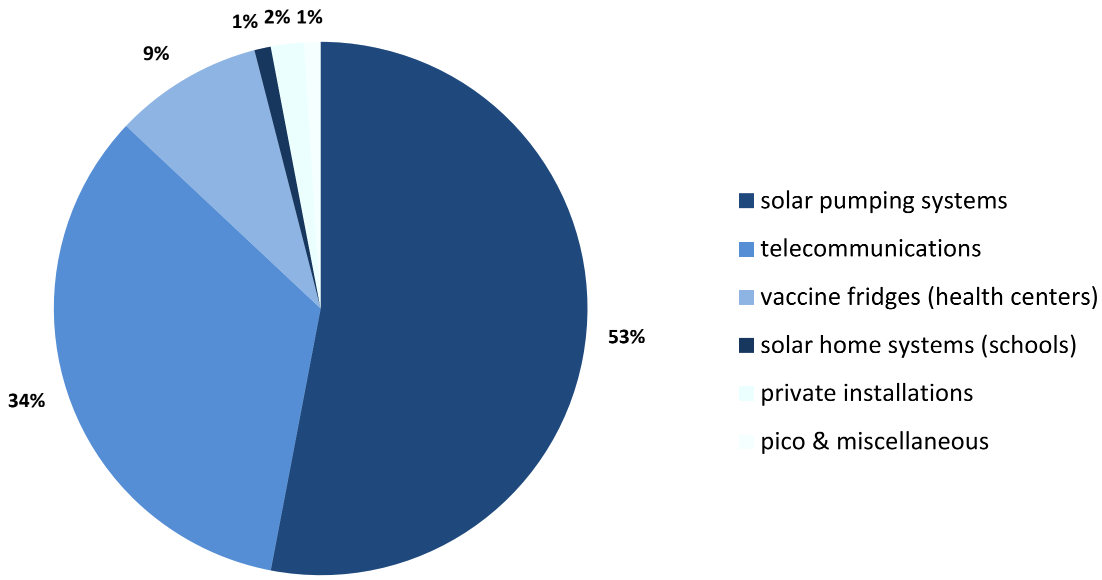

Figure 4: accumulated PV installations broken down by sector in year 2007
Source: RAACH SOLAR, data from CNES and ECREE

In order to get a new overview of the PV market situation in the year 2013, many interviews have been conducted on the demand side and as well as at the supply side.

The supply side is mainly represented by the solar professionals association "Association Professionelle de l'Energie Solaire = APE-SOLAIRE", which was created in the year 2013 on the initiative of SNV. This association represents private solar companies and operators registered in Niger. These companies are so called "system integrators" or EPCs (engineering-procurement-commissioning) who engineer tailor made photovoltaic systems for their customers, procure the material and install the turn key solution. They also provide repair and after sale service. There is no manufacturer of solar modules or components in Niger at present because of the low volume of the photovoltaic market. International supplies also come into the country based on international procurement tenders.

SUPPLY SIDE solar companies in Niger		
company name in alphabetic order	*member APE*	*main activity*
ASUSU S.A.	yes	MFI
BELKO HYDRAULIQUE	yes	EPC
DEPE SARL	yes	EPC
GLOBAL ENERGY	yes	EPC
SNV	yes	NGO
SONI NIGER	yes	EPC
SUN ENERGY AFRICA	yes	EPC
SUNTOTAL CHINA	no	EPC
TOUT HYDRO S.A.	yes	EPC
YANDALUX NIGER	yes	EPC
YASMA S.A.	yes	EPC

Figure 5: major solar companies in Niger
Source: RAACH SOLAR, data from SNV

The demand side is represented by public customers like Ministries and public services, NGO's, telecommunication companies and private customers. Niger's gross domestic product (GDP) in the year 2012 was at 3.458 billion FCFA (= €5.2 billion)[9] and the government's budget was at 1.419 billion FCFA which represents a public expenditure quota of 41%. The public sector is still a strong potential buyer of photovoltaic systems, especially for solar pumping systems by the Ministère de l'Hydraulique and solar powered vaccine fridges by the Ministère de la Santé. The construction of rural schools is often accompanied by photovoltaic battery power supply systems and tendered by the Ministère de l'Enseignement co-funded by bilateral donors.

DEMAND SIDE Niger Government Ministries	
1. Ministère des Affaires Étrangères	20. Ministère des Enseignements Professionels
2. Ministère du Plan	21. Ministère des Enseigements Secondaires
3. ministère de l'Agriculture	22. Ministère de l'Environnement
4. Ministère des Mines et Industries	23. Ministère de l'Equipement
5. Ministère du Commerce	24. Ministère des Postes & Télécommunications
6. Ministère de l'Energie et du Pétrole	25. Ministère de l'Aménagement du Territoire
7. Minsitère de l'Urbanisme et du Logement	26. Ministère de la Jeunesse & Sports
8. Ministère de l'Intérieur	27. Ministère de Tourisme et de l'Artisanat
9. Ministère de la Justice	28. Mionistère de l'Emploi
10. Ministère de l'Hydraulique	29. Ministère de la Culture
11. Ministère de Transports	30. Ministère de la Communication
12. Ministère de la Defense nationale	31. Ministère Délégué au Développement Industriel
13. Ministère de l'Enseignement Supérieur	32. Ministère Délégué au Budget
14. Ministère des Finances	33. Ministère Délégué à l'Intégration Africaine
15. Ministère de la Population	34. Ministère Délégué à la Décentralisation
16. Ministère de l'Enseignement Primaire	35. Ministère Délégué à l'Aménagement du Territoire
17. Ministère de l'Elevage	
18. Ministère de la Santé Publique	
19. Ministère de la Fonction Publique	

Figure 6: list of ministries in Niger
Source: RAACH SOLAR, data from
http://www.gouv.ne/index.php/les-ministeres/liste-des-ministeres

After the fade out of the European funded regional solar program (PRS1 & PRS2) for solar pumping systems, there are every year national and international tenders for solar pumping systems through water sanitation and supply infrastructure projects funded by the Ministry of Water, AFD and the European Development Fund. In average it can be estimated that there are between 20 to 30 pumping systems installed every year in Niger. The typical size of a village solar pumping system is between 2 and 10kWp power, so that this market section will be between 100 and 150 kWp.

[9] Agence Ecofin, http://www.agenceecofin.com

More than 100 none governmental organizations (NGO) are listed in Niger such as CARE, CROIX ROUGE, GRET, HELVETAS, OXFAM, PLAN INTERNATIONAL. Most of them work in the rural areas and are buyers of miscellaneous solar power systems for their projects. If every NGO buys 500Wp per year, the demand can be estimated at a minimum of 50 to 100kWp / year.

The most promising customers for photovoltaic power supply systems in the private sector are telecom companies. There are the mobile phone companies AIRTEL (BHARTI), ORANGE, MOOV and SONITEL. The company AIRTEL avowed itself as the market leader in mobile phone market shares in Niger. And indeed, AIRTEL moved from 1.6 million subscribers with a 66% market share in 2011 to more than 3 million subscribers by end of 2013[10]. AIRTEL's infrastructure relies on almost 300 telecom sites covering more than 12.000 villages with telecommunication services. 185 sites in rural areas have already been equipped with each 6kWp photovoltaic array, charge controllers and batteries, 100 additional sites in urban areas which already have a NIGELEC grid connection will be equipped with solar modules as grid power is unreliable. New sites will follow to increase the coverage area for mobile telecommunication. If it is estimated that AIRTEL with a 66% market share equips 30 sites per year (=180kWp) and the other telecom companies follow similar developments, the market section of the telecom photovoltaic power supplies will be at 270kWp per year.

At the end of the year 2013, there are most likely 5 million mobile phone customers in Niger. At a population of 17.6 million (2013), the mobile phone market penetration is around 28%, which offers excellent opportunities for rural electrification services. ORANGE and AIRTEL already offer to pay NIGELEC invoices by mobile phone prepayment credits. ORANGE offers for example the service "ORANGE MONEY" for financials transactions, whereas the fees for transactions between 300FCFA and 25.000FCFA are a modest 52FCFA. With the service "TICKETI NA", the mobile phone customer can buy bus tickets. With "AIRTEL MONEY" in cooperation with ECOBANK, AIRTEL offers widespread financial services such as money transfer, payment of invoices, payment of salaries. By the service "CPOUR TOI !", credit can be transferred from one mobile phone to another mobile phone customer to support friends and family.

AIRTEL sees several advantages in using photovoltaic power systems:

- lower cash-flow if solar systems are leased
- lower labor costs because of lower maintenance costs
- lower operation costs because PV is cheaper than diesel gensets
- clean energy, no noise and air pollution to neighbors
- more customers because of more sites in rural areas
- higher availability by a reliable power source, no breakdowns
- higher turnover, more profit

Solar powered streetlights are often to see in Niamey and in larger cities with LED lamp heads and with up to 4 solar modules each 50Wp. The metal pole seems to be robust, the batteries are probably underground to protect them against the hot temperatures under the solar modules. However in the night only every fifth streetlight (20%) works. The reasons are poor quality of components and a lack of after sales service. Even if there are large projects between 500 to 1000 streetlights, in average it can be estimated that not more than 200 streetlights are installed per year.

[10] Interview with Mr. Laouali Yacouba (responsable energie AIRTEL) in Niamey, 02.12.2013

Picture 1: solar powered streetlights in Niamey
Source: RAACH SOLAR

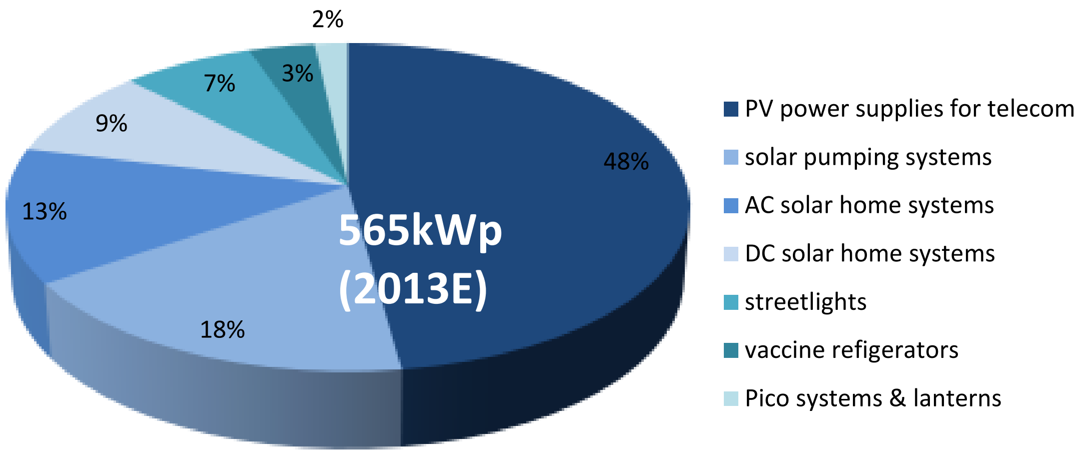

Figure 7: 2013 PV market in Niger
Source: RAACH SOLAR, estimations, empirical data

In 2013, the Nigerien PV market can be estimated at an annual market volume at around **565kWp** based on empirical data. The drivers in the market are telecommunication companies who need reliable power supplies in urban and rural areas. The large telecom portion of 48% of the market demand is pure private investment without subsidies. With an estimated overall mobile phone penetration of 28% of the population, this market will not be saturated for the coming years. It will not grow in volume but will represent a stable market demand. If other market sections such as AC and DC powered solar home systems are partially added to the telecom section, more than 60% of the photovoltaic market in Niger is private investment without subsidies. Solar pumping projects are mainly financed by large scale infrastructure donor grants in the hands of public customers.

Photovoltaic grid connected systems and large scale photovoltaic power plants are not yet implemented in Niger. Also AC mini grids as an option for large scale rural electrification are not yet seen in Niger. The overall real market of 565kWp represents only 0.1% of the potential of 367MWp. What are the reasons?

1.2.3 Regional customs duties and logistics

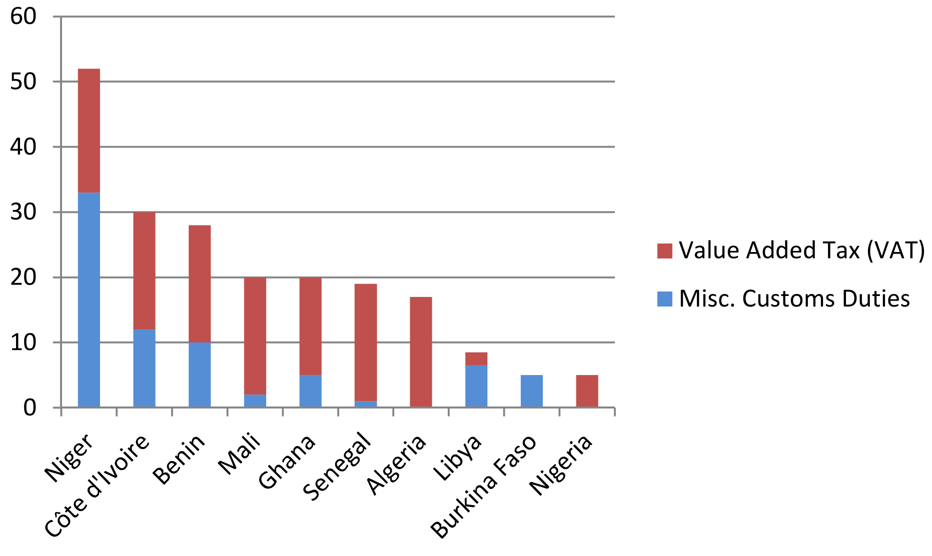

Figure 8: comparison of West-African VAT
and customs duties in selected countries in fiscal year 2013
Source: RAACH SOLAR

When it comes to the end customer price, solar modules and most of their components such as batteries, charge controllers, inverters are taxed in Niger as luxury products with 52% on top of the landed price at border or airport. Niger as a member of the ECOWAS is also in strong disaccord with the Economic Community of West Africa States (ECOWAS, in French CEDEAO). The target of ECOWAS is the customs, monetary and economic union of the member states. A part from statistical supplements on the import prices, Mali, Senegal, Algeria, Burkina Faso and Nigeria have exonerated the solar modules from import duties, Burkina Faso even from the VAT. Solar modules are considered in these countries as a strategic product to promote rural electrification. In Niger, the high import duties are a real barrier for further market development. What are the consequences for Niger?

1. No further growth in the photovoltaic market compared to international market developments.
2. No further development of private sector and private market demand for solar power systems.
3. Discrimination of solar power systems against fossil fuels, standard motor generators or even against electricity imports from Nigeria.
4. Clandestine illegal imports of solar products from neighbor countries such as Benin, Nigeria and Burkina Faso.
5. High electricity production costs from photovoltaic systems.

International Custom Codes	
solar modules, crystalline, thin film	85414090
charge controllers	90328900
batteries OPzS	85072020
batteries OPzV / AGM	85072080
inverters < 7kVA	85044084
inverters > 7kVA	85044088
lamps CFL, AC and DC	85392998
lamps LED, AC and DC	85392998
lamps, streetlights	94054099
solar powered refrigerators	84183020
medical refrigerators for vaccines	84185090
pumps, submersible	84137029
DC / DC converters	85044084

Figure 9: international custom codes for solar components
Source: RAACH SOLAR

The government of Niger has the possibility to exonerate certain special components from import duties - like other West African governments already do - to privilege the use of photovoltaic power systems. Figure 9 gives an overview of the major components used in photovoltaic systems with their international custom codes.

To import solar components from the major production regions, the list below gives an overview on the sea freight costs:

1) Container 20" Europe to Niamey = 4800,00 Euro
2) Container 40" Europe to Niamey = 5660,00 Euro
3) Container 20" China to Niamey = 5181,00 Euro
4) Container 40" China to Niamey = 6380,00 Euro

There are around 100kWp crystalline solar modules in a large 40” shipping container. Calculated on an average market price of 0,56€ / Wp for industrial quality solar modules, the container is worth 56.000€. The transport cost from Europe, America or Asia to Niamey is between 10% and 12% of the goods value.

1.2.4 PV market outlook

There are approximately 10 private companies in Niger who engineer, procure, install and commission turnkey photovoltaic systems who share a cake of only 585kWp. It is extremely difficult for private solar companies to create enough turnover and margin to live only on solar power engineering and sales. Most of these companies take photovoltaic systems as a side business. All headquarters are based in Niamey and some have sales points in other larger cities as long as they can afford it. One of the private operators YANDALUX sees the major barriers as follows [11]:

- There is no market for grid connected PV systems
- Financial interest rates for bank credits are too high, e.g. 18% p.a.
- Long term credits are not available, e.g. 15 years.
- Rural population have no bank accounts and are not bankable
- Lack of information for end customers, a marketing campaign is missing
- Lack of information for middlemen & dealers on PV systems
- No funds available for marketing campaign and trainings
- Solar modules should be exonerated from import duties and taxes

At a market volume of 585kWp in an intensive competitive environment, it is difficult for private solar companies to be profitable and sustainable without a constant private market demand and without regular public tenders.

The UNDP will come up with the project PRASE FEM from 2014 to 2017 which will also fund photovoltaic power systems[12]. The financial volume will be $1.7 million USD funded by GEF (Global Environmental Facilities) plus $200.000 per year (over 4 years) from UNDP. PRASE (Programme Régional D’Accès Aux Services Énergétiques) will have an institutional component and as well an operational component. First it will improve the institutional environment for the distribution of renewable energies, second it will help to promote and distribute products related to energy savings (e.g. lamps) and replace 150 diesel powered pumps by photovoltaic pumping systems in the rural community of Safo. Also new PV technologies will also be introduced such as solar powered back up systems, but will not be limited to those. In a first pilot project, the UNDP financed so called “plateformes-multifonctionnelles” which are power systems to supply several applications for the benefit of the rural population such as mills, pumps, mobile phone charging, lighting etc. If it is not a conventional power system, it is an AC solar home systems.

[11] Interview with Mr. Moussa Istaf (Yandalux Niger) in Niamey, 28.11.2013
[12] Interview with Mr. Elh Mahamane Lawali (UNDP) in Niamey, 03.12.2013

Picture 2: UNDP “platesformes multifonctionnelles”
Source: RAACH SOLAR

The UNDP PRASE project is paralleled by the PASE SAFO project. The PASE project electrifies more than 70.000 inhabitants in the community of Safo (region Maradi) basically with grid extension[13] and photovoltaic power systems. The allocated funds are €3.4 million originate from the European Union (75%) and UNDP (25%). The maximum photovoltaic power share in this project can be estimated at 500kWp.

A more promising, but also late solar project comes from the Indian Government with three components. The Indian government allocated funds of US$34 million to the CDAO under the conditions that the material supplies come from Indian manufactures.

LOT1 ($10 million, 2014-2015) will electrify 50 villages in the regions Dosso, Tao, Tillaberi and provide community services (schools, health centers etc.) as well as portable solar lanterns.

LOT2 ($9.5 million, 2014-2015) will electrify 30 villages in the regions Maradi, Zinder, Difa, Agadez and provide community services (schools, health centers etc.).

LOT3 ($24.7 million, 2014-2015) will finance a 5MWp photovoltaic grid connected power plant.

The project has not yet started so that it can be estimated that it will further delay. The project will be decided by national tenders in India and if the tender process starts in 2014, the projects will not

[13] Interview with Mr. Bello Nasseaou (renewable energy director, Ministry of Energy), 02.12.2013

finish before 2016. At current market prices in India, LOT3 with $24.7 million will not only be able to finance a 5MWp but a 10 to 15MWp photovoltaic power plant.

The largest photovoltaic project in Niger is the Goro Banda power plant in Niamey. This grid connected power plant will have a total capacity of 100MW, whereas 80MW will be conventional thermal power and 20MWp will be photovoltaic power. The financing is set up by the BOAD (Banque Quest Africaine de Développement) with FCFA 50 billion, by the BID (Banque Islamique de Développement) with FCFA 17 billion and a contribution by the Nigerien Government. The feasibility study was financed by the AFD.

The UNDP project will involve small and medium sized Nigerien enterprises, but there is little potential for the Indian and Goro Banda project. The large scale photovoltaic power plant projects in Niger are important to boost the photovoltaic market, but will not have a large impact on rural electrification. Within the next five years, newly **30 to 40 MWp** of photovoltaic power can be installed additionally in Niger, which will lift the current market size from 565kWp to more than 5MWp annually.

2. ENERGY SUPPLY IN NIGER

2.1 situation of energy supply in Niger

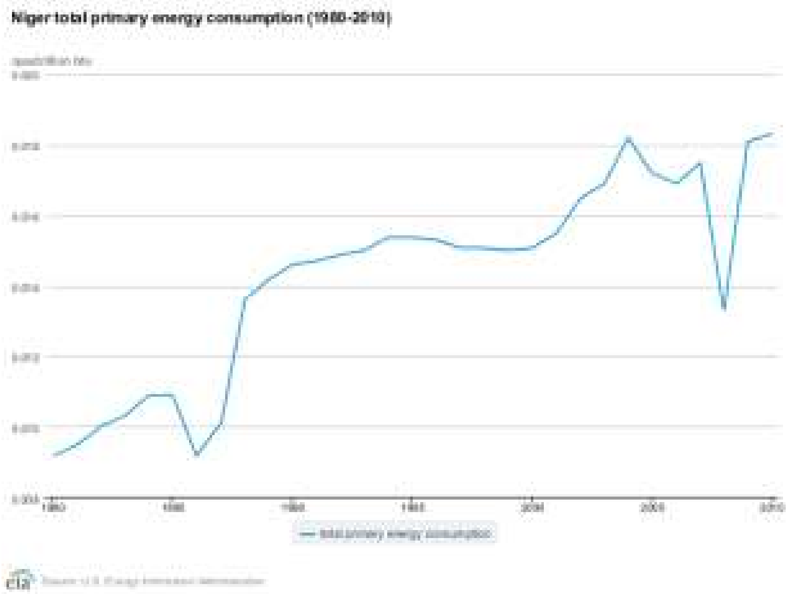

Figure 10: primary energy consumption of Niger
Source: US Energy Information Administration; www.eia.gov

Niger's primary energy consumption has been steadily growing over the last years and will continue to grow with the economic recovery. The total primary energy consumption was 0.0183 quadrillion btu (2010), which ranked Niger on position 183 of the worldwide scale. The primary energy consumption comes mainly from petroleum (55%), followed by coal (24%) and biomass (20%)[14], however there are contradictory sources of the renewable energy share by biomass. The IRENA[15] puts the biomass (wood) share of the Nigerien primary energy consumption at 93% excluding the electricity trade.

Niger depends on oil imports and pays a heavy bill in hard currency. In 2010, Niger imported 5.136 barrels crude oil and petroleum products per day. With the discovery of oil resources in Niger, this situation will change. Niger is independent from coal imports and with proven reserves of 77 million short tons of anthracite and bituminous largely exceeds its current annual coal consumption of 0.2 million short tons.

[14] http://niger.opendataforafrica.org
[15] IRENA country profile Niger

2.2 The electricity sector and its actors

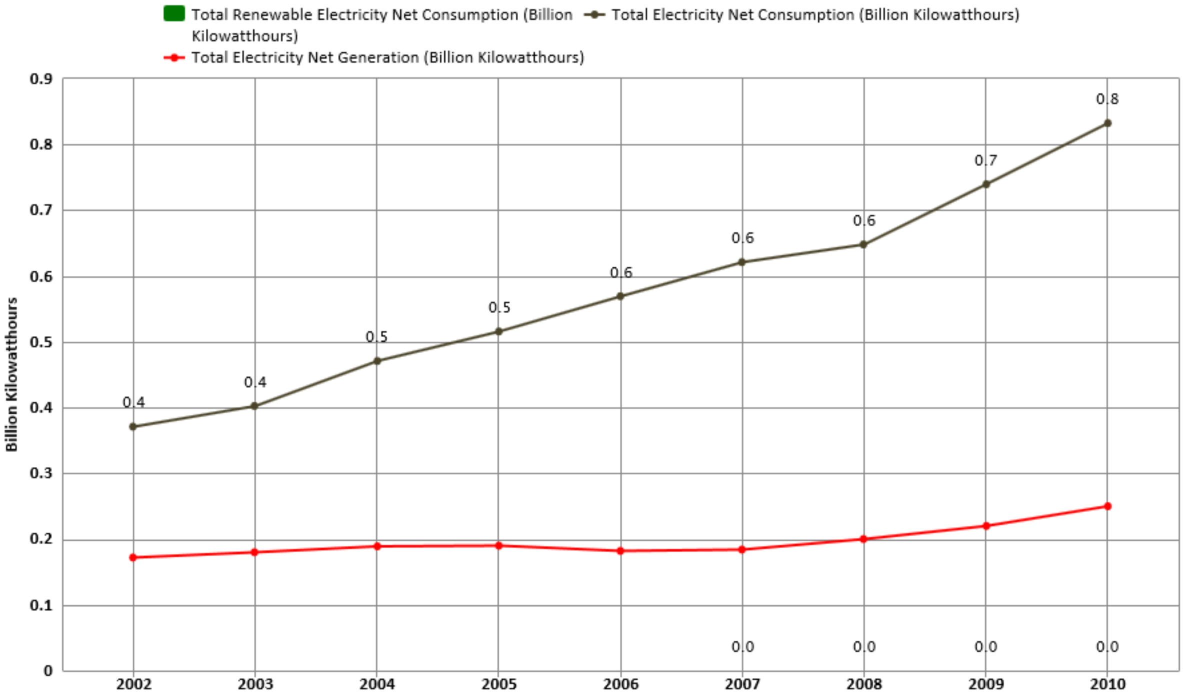

Figure 11: electricity generation and consumption of Niger
Source: http://niger.opendataforafrica.org

The gap between electricity generation and electricity consumption constantly widens in Niger as shown in diagram 10. The national electricity company NIGELEC (Société Nigerienne d'Électricité) has sold 649 GWh in 2010[16], from which 551 GWh (=85%) was imported from Nigeria, 32GWh (=5%) was purchased locally mainly from mining companies and only 66GWh (=10%) was produced nationally. The total installed production capacity is 115MW diesel generators in different locations, only 7MW diesel grid is installed in rural areas. The population with access to electricity is 45% in urban areas and only 1% in rural areas[17]. 400 out of 11.000 villages are electrified. NIGELEC says that it has around 230.000 electricity subscribers, 95% of them are private households. If an average Nigerien household consists of 8 persons, there are roughly 2.1 million households in Niger. 80% of Nigeriens population lives in rural areas. Under these conditions, the real electrification rate is more likely to be at 10 to 15% of the total population which puts Niger's electrification rate of 15% much lower than the mobile phone penetration rate of estimated 28%.

Niger's economy is likely to change dramatically in the next decade and as well there are big opportunities for the electricity sector. Four major electricity generation projects are currently developed which will dramatically reduce Niger's dependency on electricity imports.

[16] NIGELEC, www.nigelec.ne
[17] IMF „Niger: Poverty Reduction Strategy Paper", April 2013

Electricity generation projects (2014 – 2020):

1. Photovoltaic power plant “Guesselbody” 20MWp
2. Diesel powered thermal plant “Gourou Banda” 80MW
3. Coal fired thermal power plant “Salkadamna” 200MW
4. Hydroelectric power plant “Kandaji” 130MW

NIGELEC is the only player and state owned electricity company which was founded in the year 1968 and executes its monopoly on electricity production, transport and distribution. The company SONICHAR, created in 1978, produces electricity for mining companies in the Anou Araren coal mine, but distributes electricity through the grid of NIGELEC which is rented to SONICHAR.

NIGELEC’s purchase price of electricity from Nigeria is extremely low at 15,70 FCFA / kWh (=2,3 cent € /kWh)[18] and certainly no motivation to invest in own production capacities as electricity production costs at market conditions are much higher. The electricity supply from neighbor country Nigeria is not stable and the electricity supply in Niger is subject to frequent outages. Nigeria also comes under immense pressure from investors to privatize the electricity sector and offer market prices. It is uncertain how long the electricity price from Nigeria will be as low as in the year 2013.

The electricity sales price from NIGELEC to the customers is regulated by law and was fixed in the year 2010[19] to the price of 59,45 FCFA / kWh (=9 cent € /kWh) for private households and increases to 79,25 FCFA / kWh for higher connection powers (=12 cent € /kWh).

NIGELEC was a profitable company in the year 2012/2013 with a turnover of 50 billion FCFA (=75 million €) and a profit of 1 billion FCFA (= 1.5 million €). It registered around 1100 employees and is headed by the general manager Mr. Halid Alhassane.

2.3 local policy, rules and regulations

2.3.1 The Electricity Act

The national electricity company NIGELEC is subordinate to the Ministry of Energy and Petrol. There is a regulation body for all issues concerning electricity. This government body is the ARM, the Authority for the Multi sectoral Regulation (Autorité de Régulation Multisectorielle). The official statements by the ARM are published with 1 month after the request for clarification.

The major law is the electricity bill (“Code d’électricité de la République du Niger”), code no 2003-04 dated January 22nd, 2003, which gives the monopoly of the production, transport and distribution to the public sector as stipulated in chapter3, article no 4. Power supplies for telecommunication and for R&D purposes are excluded from these regulations.

[18] Interview with AFD in Niamey, 29.11.2013 and NIGELEC
[19] République du Niger, Présidence de la République, Ministère de l’Energie et du Pétrole „décret tarif social“

In article 6, the state can delegate electricity concessions especially in the case for rural electrification to incorporations based in Niger.

In chapter 4, article 42 stipulates that investments especially in means of production for rural electrification are exonerated from all import duties. It is not said, who will assign this exoneration. It might be that the Ministry of Energy and Petrol has to give its signature and as well the Ministry of Finance before it comes to an exoneration. This is an opportunity for investments in rural electrification, but as well a real challenge for the investor to get the approval from the Ministries.

Article 44 enables companies or private persons to generate electricity for self consumption as long it does not exceed 10kW. If the generation capacity exceeds the 10kW, the producer has to ask through a delegate (authorized agent by the Ministry) an authorization from the Minister of Energy.

Courte Utilisation				
Code Tarif	Puissance souscrite	Redevance fixe FCFA/mois	Tranche	Prix Energie FCFA/kWh
Domestique 330	3kW	750	0 à 50 kWh	59,45
Commerciaux 331	3 kW	750	-	79,25
332	6kW	1 500	-	79,25
333	12kW	3 000	-	
334	18kW	4 500	-	
335	30kW	7 500	-	

Longue Utilisation			
Code Tarif	Puissance souscrite	Redevance fixe FCFA/mois	Prix Energie FCFA/kWh
321	3kW	3 000	70,71
322	6kW	6 000	
323	12kW	12 000	
324	18kW	18 000	
325	30kW	30 000	

Figure 12: electricity tariffs for low voltage for the years 2012-2014
Source: Nigelec

2.3.2 ANPER

Inside the MEP, there is the CER (Cellule d'Électrification Rurale), coordination and management of all international and national actions concerning rural electrification in Niger.

The electricity code from the year 2013 will probably be revised in the year 2014[20]. A rural electrification agency called ANPER has already been created in 2013 managing its own financial funds starting from the year 2014. The general manager has not yet been appointed by end of 2013. The role of ANPER will probably be the regulation of public private partnership projects for rural electrification, similar to the Senegalese Rural Electrification Agency ASER. ANPER could also administrate concessions and international tenders for rural electrification in specific areas and regions in Niger. A concession is a delegation of exclusive rights in a given area by the state or a public body to a company or person for a limited period of time to exploit and to develop a public service at its own costs and risks and to get remunerated by the end users.

The ANPER will give priority to renewable energies and collaborates closely with the PRASE / PASE project. The funds for the ANPER will probably also come from the UNDP PRASE / PASE project. The planned budget is 9 billion FCFA per year (= 13 million €). The objective of ANPER is the electrification of 50 villages per year by mainly solar power. Because of administrative delays, the objective to increase the rural electrification rate to 25% by the year 2015 will not be achieved.

2.3.3 Renewable Energy Act

The directorate of Renewable Energy and Domestic Energy at the MEP is involved in the preparation of a renewable energy act with fixed feed-in tariffs in 2014[21]. But it is not likely that individuals, private investors or companies will get access to the public grid, invest in photovoltaic systems to feed their electricity into their grid and get remunerated by NIGELEC.

Photovoltaic power systems have achieved grid parity in Europe and countries such as Germany prepare to stop feed-in tariffs in the year 2014 by revising the Renewable Energy Act (EEG). The European Union will come up in the year 2014 with new guidelines for net-metering. Net-metering is a system to compensate for electricity generated by photovoltaic systems without paying necessarily a feed-in tariff. The electricity from PV systems is fed into the grid via a bidirectional energy meter and is offset against the electricity received from the grid. If more solar electricity is fed into the grid as consumed by the household, the excess production can be transferred into the next billing period. But even if the household produces more photovoltaic electricity then consumed over a year, the household needs to pay a monthly lump sum as it uses the public grid as buffer storage instead of using batteries.

[20] Interview with Mr. Halilu Kané, Ministry of Energy and Petroleum
[21] Interview with Mr. Bello Nassourou, director of renewable Energy, MEP, 03.12.2013

PV SYSTEM CLASSIFICATION	FEED IN TARIFF PER KWH (without VAT)
Up to 10kWp	13,12 cent €
Between 10kWp and 40kWp	12,44 cent €
Between 40kWp and 1MWp	11,10 cent €
Between 1MWp and 10MWp	9,08 cent €

Figure 13: feed-in tariffs in Germany as per April 2014 (E)
Source: RAACH SOLAR, BSW

2.4 Major barriers of photovoltaic systems

Institutional - Monopoly of energy production, transport and distribution - No feed in law for private investors - No net metering allowed - NGO's and bilateral donors are concentrated on food programs but not on energy issues - Too much government driven and dominated market which does not attract private investments - No priorities for renewable energies	Market - Small PV market size does not allow solar companies to have a sustainable business - Large scale projects exclude small and medium sized enterprises (SME) from market participation - National and international tenders do not privilege local content - Not enough awareness in the market (households, politicians) about financial advantages of photovoltaics
Financial - Highest import duties in West Africa make solar power unaffordable - Lower import duties for fossil fuels and diesel generators - No special credits for private households - High interest rates (20%) for private consumer credits in spite of fixed FCFA-EURO exchange rate - Subsidized electricity deliveries from Nigeria below production costs	Technical - CNES is not equipped enough for national quality tests of e.g. modules, lamps, batteries according to international standards - Lack of quality controls after completed PV installations

Figure 14: summary of market barriers
Source: RAACH SOLAR

3. MARKET STRATIFICATION

3.1 Stratified market sector analysis

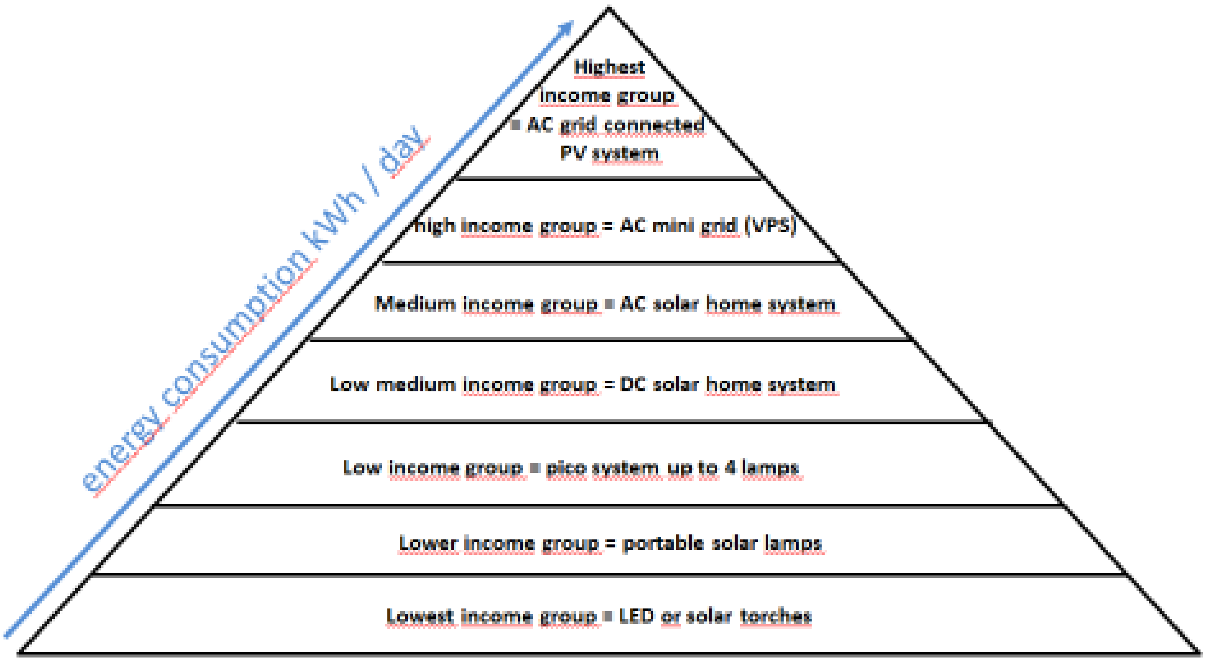

Figure 15: PV system technology and income groups
Source: RAACH SOLAR

Figure 15 shows a pyramid structure of theoretical seven different technical options of photovoltaic systems to electrify rural areas. The higher the income group, the higher the energy consumption. This figure does not reflect the income distribution by income group.

NO	INCOME GROUP	PV TECHNOLOGY	ENERGY CONSUMPTION	DAILY SPENDINGS
1	highest income group	AC grid connected PV system	> 10kWh / day	> 3€
2	high income group	AC mini grid	1201Wh - 10000Wh / day	2,01 - 3,00 €
3	medium income group	AC solar home system	301Wh - 1200Wh / day	1,51 - 2,00 €
4	low medium income group	DC solar home system	61 Wh - 300Wh / day	1,00 - 1,50 €
5	pico systems up to 4 lamps	DC pico system (4 lamps)	31Wh - 60Wh / day	0,76 - 1,00 €
6	portable solar lamps	DC portable solar lamps	5Wh - 30Wh / day	0,51 - 0,75 €
7	LED or solar torches	DC LED or solar torches	2Wh / day	0,10 - 0,50 €

Figure 16: income groups, PV system technology & daily spending
Source: RAACH SOLAR

According to international statistics[22], Niger is ranked last place in the world with the worst uneven income distribution. This uneven income distribution is calculated and shown by the “GINI” factor of around 44. 60% of the population lives under the poverty level, 44% of the population has to live with less than 1.25 USD per day. The market size of the technical options lowest and lower income group is consequently 60% of Niger’s population.

The lowest income group’s energy spending goes to batteries for LED lights and torches, sometimes the purchase of a torch with a built in small solar module. The cost of a standard LED battery lamp is in Niger around 1000 FCFA (1.50 €). One pair of AAA MIGNON batteries is 250 CFA. A torch owner spends around 500CFA (0.75 €) per week for lighting services[23].

SNV’is currently preparing a large scale portable lamp project for Niger, which correctly targets the largest income group of Niger. Three different lamp types from the manufacturer GREENLIGHT are offered: lamp SUNKING ECO (0.7Wp), SUNKING MOBILE (1.6Wp) and SUNKING PRO (3Wp). These lamps meet the “lighting global” minimum quality standard set out by the Worldbank-IFC program “Lightin Africa”. The three basic features of the lamps are a typical 1.5Wp solar module, a modern rechargeable battery and a LED bulb. The largest lamp is the In-Diya 2 with a 10Wp solar module.

Pico PV systems are small photovoltaic systems with a power output of up to 10Wp. Portable solar LED lamps like the SUNKING are also pico systems, but should be differentiated from fixed installations of pico systems which can light up several rooms of a building. The pico solar home systems come with a separate solar module which is installed outside on the roof of a building and the typically four lights are installed inside the house and conntected to a charge controller to protect the battery against deep discharge. The charge controller and battery are in a closed box, sometimes, the pico solar home systems are also sold with solar modules, charge controller, lamps, cables but without battery to reduce transport cost, import duties and increase warehouse storage periods.

Before the pico systems were brought to the market thanks to new innovative technological developments in LED technology and lithium batteries, the basic electrification of rural households was done by so called “solar home systems (SHS)”. A typical solar home system is a 12V direct current solar system with a 50Wp solar module, a 12V-6A charge controller, a 12V-80Ah lead-acid or lead-gel battery and four 12V-7W compact fluorescent lamps. Because the 50Wp module generates between 150Wh to maximum 300Wh per day depending on the installation site, these solar home systems also allow the connection of a 12VDC radio or 12VDC television set. The price of a DC solar home system is for many rural households not affordable without a financial down payment system. To improve the financial and technical control of a down payment system, charge controllers with prepayment technology are used. This report will highlight the advantages and disadvantages of prepayment technology in the following chapters.

Many users of DC solar home systems complained that they do not have the possibility to connect standard 230VAC/115VAC appliances such as TV sets, video recorders, fridges, electric irons etc. DC solar home systems are upgraded by an DC/AC inverter to satisfy the demands for the AC appliances. But the upgrading also increased the daily energy consumption and more solar modules and batteries are added which also leads to a significant price increase.

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[22] http://liportal.giz.de/niger/wirtschaft-entwicklung/
[23] Visit of Bossey Bangoue village, Niger, 29.11.2013

AC mini-grids already start from solar generator capacities of 5kWp with a single phase 230VAC distribution and can go to several hundreds of kWp with a three phase AC electric grid. The advantage of the AC mini grid is that solar electricity is distributed by a power line which runs through a village and supplies different customer groups such as affluent private subscribers, small scale businesses such as welders, shops and also community services. These community services are health centers with vaccine storage capacities, schools, public administration buildings such as the town hall and public street lighting. The electronic control systems of these AC-mini grids can also drive electric pumps with excess electricity (when the batteries are fully charged) to lift up water from deep wells to supply the village with drinking water and irrigation water for agricultural activities. AC mini grids are a real contribution to the development of the rural population because they support businesses to create additional income through productive and commercial activities. Thanks to the modular and redundant design, AC mini grids accompany the village's future development by easily adding electricity generation capacities.

AC mini grids can be interconnected between the villages and electric grids can be built up. AC mini grids can also be connected to the public grid when the public grid arrives in the village. Standard grid connected photovoltaic systems without battery storage need the presence of an electric grid. During daytime these systems feed their electricity via an energy meter into the grid and during nighttime the electric grid supplies back the households. Feed in tariffs, which are guaranteed prices per kWh by law over a specified period of time and paid by the electricity company, guarantee an economic operation of photovoltaic systems. As photovoltaic grid connected power has already broken even against commercial electricity prices, many countries move away from feed in tariffs and introduce a system of net-metering. Net-metering means that the owner of a photovoltaic system sells its electricity to the public grid and receives electricity back from the public grid when he is in need for electricity. The balance of selling and buying is registered by a two ways energy meter whereas today the sales price is inferior to the buying price. The buying price includes the storage capacity of the grid which the PV system owner has to pay. Grid connected photovoltaic systems for rural electrification can only be useful in urban areas to stabilize the unreliable public grid or to attract private investment to increase PV power generation capacities in AC mini grids.

Figure 17 below gives an overview on PV system prices by system technology. The specific price in €/Wp is higher for smaller system compared the larger systems. However the trend for AC-mini grids show that the system price is higher compared to AC solar home systems or grid connected PV system because the cost for storage and the AC grid is included in the price.

The shown prices are typical dealer prices, so it can be estimated that transport, installation services, import duties and VAT might double the system price until the system is in the hands of the user. The electricity price per kWh depends on the specific system costs (US$ / € /kWp) but as well on the lifetime of the single components of the PV system. The pico systems show the highest specific cost per Wp, however here the electricity generation costs are not that important because the user wants to benefit especially from the lighting and mobile phone charging services.

PV system prices by system technology

NO	INCOME GROUP	PV TECHNOLOGY	COMPONENTS	TYPICAL POWER RATING [Wp]	TYPICAL DEALER PRICE	PRICE / Wp
1	highest income group	AC grid connected PV system	solar modules, on roof module support, grid tie inverter, energy meter, accessories	5.000,0	5.000 €	1,0 €
2	high income group	AC mini grid	30kWp solar module, on ground support, inverter/chargers, 48V-4500Ah battery, 1.5km three phase grid grid tie inverter, energy meter, accessories	30.000,0	90.000 €	3,0 €
3	medium income group	AC solar home system	1kWp solar modules, 24V-30A charge controller, 24V-400Ah battery, 24V-500W inverter, 4 x lamps, accessories	1.000,0	2.000 €	2,0 €
4	low medium income group	DC solar home system	50Wp solar module, 12V-6A charge controller, 12V-80Ah battery,4 CFL / LED lamps, support, accessories	50,0	300 €	6,0 €
5	pico systems up to 4 lamps	DC pico system (4 lamps)	10Wp solar module, 4 x LED lamps each 3W, 12V-7Ah Li-battery, switches, accessories	10,0	70 €	7,0 €
6	portable solar lamps	DC portable solar lamps	solar module 0.8 to 2Wp, 1 x LED lamp, Li-battery (5 to 10h running time), stand, accessories	1,5	12 €	8,0 €
7	LED or solar torches	DC LED or solar torches	torch with built in solar module, NiCd oder NiMH battery	0,5	5 €	10,0 €

Figure 17: PV system prices by system technology (2014)
Source: RAACH SOLAR

3.2 Stratification according to EnDev

The IEA defines in its World Economic Outlook from the year 2012[24] an electrified household as a rural household which has a minimum level of consumption of 250kWh / year and 500kWh / year for an urban household. The way of electrification can be grid connected or by off grid systems.

An energy consumption of 250kWh per year is a daily energy consumption of 0.68 kWh or 680Wh per day. The minimum necessary photovoltaic power to cover this energy consumption would be **200Wp solar power and 12V-180Ah battery storage capacity per household in the context of Niger[25]**.

The SE4ALL initiative does not give precise values compared to more arbitrary definition by the IEA and defines it as a universal right for every household to have access to modern sustainable energy by the year 2030. But how?

[24] www.iea.org/publications
[25] Result of PV system sizing by software PV designer, Raach Solar

The EnDev gives a more sophisticated answer to definition[26] of access to modern sustainable energy and is in line with the SE4ALL initiative:

- LIGHTING: All household members have at least 5 hours light per day
- COMMUNICATION: Households can use a land line or a mobile phone for communication
- INFORMATION: Households can use radio and/or small TV for several hours a day
- COOKING: Households have cooking facilities

EnDev sees the access to energy as a constant process of developing a households increasing energy demand and defines different energy levels so called "tiers"."In general, a tier (pronounced TEE-er ; from the medieval French *tire* meaning rank, as in a line of soldiers) is a row or layer in a series of similarly arranged objects. In computer programming, the parts of a program can be distributed among several tiers, each located in a different computer in a network. Such a program is said to be *tiered* , *multitier* , or *multitiered* ".[27]

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Indicative electricity services	-	Task lighting + Phone charging or Radio	General lighting + Air circulation + Television	Tier 2 + Light appliances	Tier 3 + Medium or continuous appliances	Tier 4 + Heavy or continuous appliances
Consumption (kWh) per household per year	<3	3–66	67–321	322–1,318	1,319–2,121	>2,121

Figure 18: Mapping of tiers of electricity consumption to indicative electricity services
Source: Global tracking framework, SE4ALL, page 101

TIER	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
max. energy consumption in kWh per year	3	66	321	1318	2121	> 2121
min. energy consumption in kWh per year	3	3	67	322	1319	> 2121
min. energy consumption in kWh per day	0	0,008	0,184	0,882	3,614	3,614
min. energy consumption in Ah (at 12V)	0	0,7	15	74	301	301
min. Wp photovoltaic capacity needed	0	2,2 Wp	50 Wp	250 Wp	1000 Wp	1650 Wp
min. battery storage capacity needed	0	2,3 Ah	50 Ah	230 Ah	940 Ah	1510 Ah

Figure 19: Minimum photovoltaic power needed by tier
Source: RAACH SOLAR, PV designer software

[26] 3rd symposium „small PV applications", OTTI 2013 proceedings, page 28
[27] Definition by Margaret Rouse, source: WhatIs.com

Figure 18 shows the stratification of rural households according to their electricity consumption. Tier 1 would satisfy the first energy consumption level which allows a rural household to have access to lighting, communication and information services. The minimum requirement for lighting and mobile phone charging is in the range of a 2Wp solar module, but 2Wp would not support a radio or television. If additionally a TV or radio should be supplied, a minimum of a 10Wp pico system is necessary.

4. PHOTOVOLTAIC AC MINI GRIDS

4.1 Technological set up

AC mini grids can be built up everywhere they are independent from the public electricity grid and build up their own single phase or three-phase electricity grid. There are basically two different technological concepts, the AC-network design and the DC-network design. The central power line is either an alternating current line or a direct current line. In other words it is either an AC coupled system or DC coupled system.

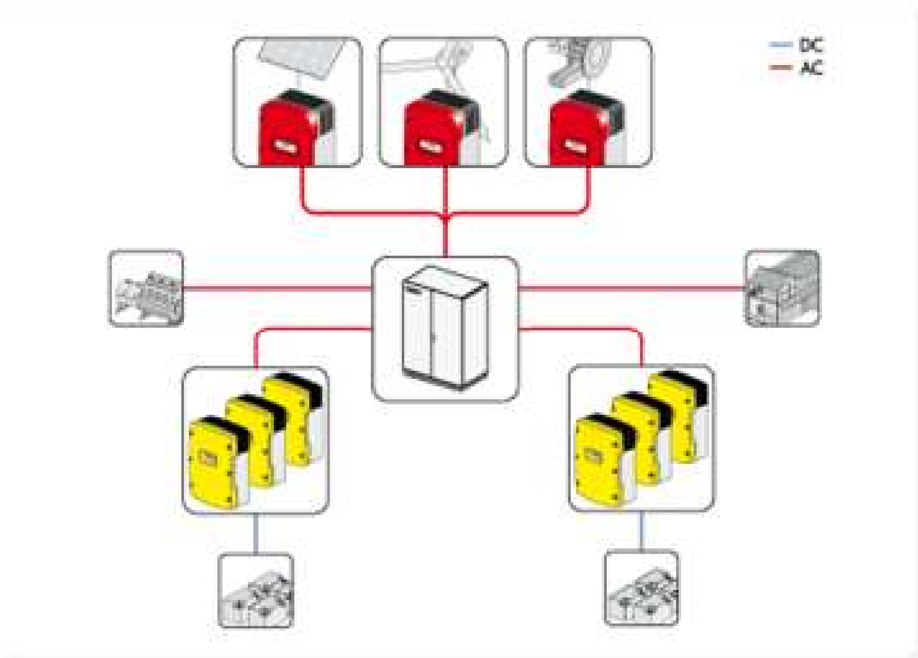

Figure 20: AC mini grid in an AC coupled system
Source: SMA, www.sma.de

Manufactures such as SMA, STUDER and SCHNEIDER ELECTRIC offer AC coupled grid tie inverters and inverter chargers. The concept is that solar modules feed the electricity into an AC grid and supply directly the load during daytime. With the surplus of production, the batteries are charged simultaneously by the AC/DC inverter chargers. If there is not enough power available or during nighttime to supply the loads, the inverter charger will discharge the battery to give the power back to the grid. Figure 20 shows from the top the various power sources which can feed their electricity into the AC grid such as solar modules, wind power generator, hydroelectric power or even a diesel genset (shown left). The central AC switch box distributes the power in the system. The real brain of the mini grid system however is master device of the inverter/chargers (shown in yellow). The AC grid is permanently available and supplies the load (shown right). The only risk is that the system is not properly designed or the power consumption of the loads increase significantly. In this case the central distribution box will switch off the load to protect the battery (shown on the bottom) against deep discharging.

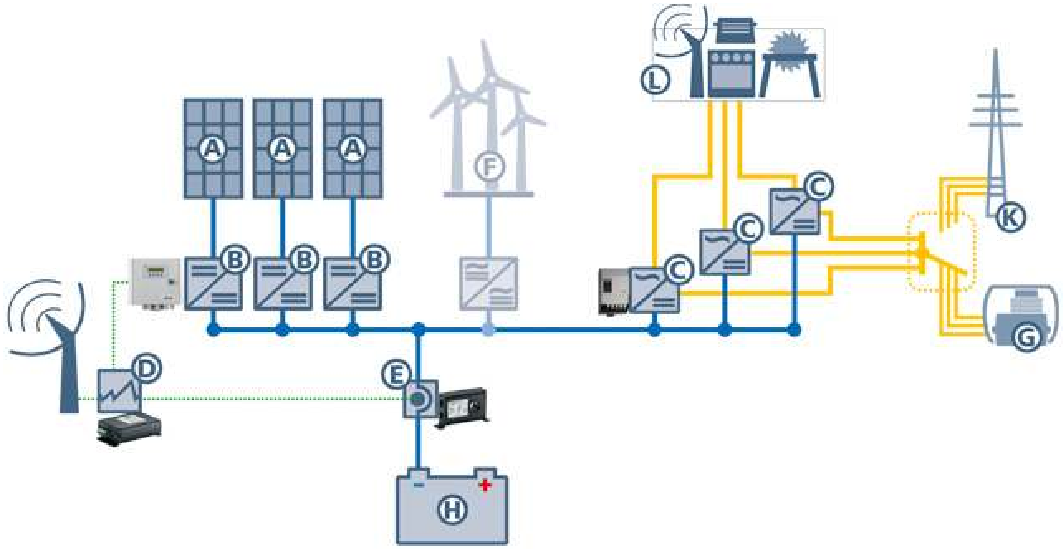

Figure 21: AC mini grid in a DC coupled system
Source: STECA, www.steca.de

Especially manufacturers of solar charge controllers such as STECA , PHOCOS and MORNINGSTAR offer DC coupled mini grids which still need an inverter at the end to supply the AC loads as shown in figure 21. On the left side, there are several solar module sub arrays which charge via a solar charge controller (DC/DC converter) the battery. The central power line is a DC network. Closely situated to the batteries, three inverters convert the DC voltage in AC voltage to supply the load (as shown right). Either the electric grid or a diesel genset, if available, can be used as a back-up power source.

The DC coupled mini grid is more efficient than the AC coupled mini grid if the load is mainly used during nighttime and during daytime the batteries are charged. However the main target of a mini-grid is to encourage small businesses and they mainly run during daytime. If the photovoltaic array goes beyond 30kWp up to several 100kWp, the regulation of the mini grid is easier with AC cables than transporting 2000A to 5000A direct current at 48VDC.

ADVANTAGES OF MINI GRIDS

- reliable power if properly designed
- clean and silent power with photovoltaic power
- no air, soil and sound pollution to the environment
- modular and redundant design increases reliability (24H/24h – 7d/7d)
- easy to increase power generation capacity
- use of different auxiliary power sources possible (wind, diesel, hydro, grid)
- standards household appliances can be used (3 x 400/ 230VAC)
- management: users become subscribers with individual energy meters
- users do not need to pay investment in advance
- after sales service on one central place
- distributed power and no waste of electricity: households who do not consume power in the village can be used by other households

DISADVANTAGES OF MINI GRIDS

- risk for owner: financing of system depends on subscribers willingness and capacity to pay
- ownership: owner of PV system and village must be separated to maintain discipline in the management system
- monthly money collection is costly or can be done by prepayment technologies
- unclear who pays for public services such as street lighting, health centers, school
- high investment cost for electric grid
- only customers who can afford to pay significantly more than 10€ per month can become customers. This would correspond to customer level TIER 3, 4, 5 according to the EnDev classification

4.2 Photovoltaic system layout and simulation

The photovoltaic system design is based on a 30kWp photovoltaic generator, which will produce in Niger around 50.422kWh per year according to the PV system sizing by the software *SMA OFF GRID configurator* or 1741kWh /kWp / year. But how many kWh can really be distributed and sold to the subscribers?

It all depends on the load profile. In this simulation 50% of the electricity is used during daytime and 50% during night time. The electricity which is produced by the solar modules is subject to conversion losses by the inverters, inverter-chargers and batteries. The simulation shows 37102kWh as distributed electricity or approximately 101kWh per day. But how many subscribers are reasonable?

If the TIER 3 to TIER 5 category is targeted, the household consumption must be between 0.8kWh and 3.6kWh / day which correspond to 28 households (TIER 5) up to a maximum of 126 households (TIER 3). The 30kWp AC mini grid can supply a maximum of 126 households in the TIER 3 category. As a Nigerien household has 8 members, a 30kWp PV system will fit to electrify theoretically a village of 8 x 125hh = 1000 people.

Not every household can afford to buy electricity and an AC mini grid may have to target a smaller amount of subscribers with a higher energy need but with a higher income. For economic reasons, not all households in a village are electrified by the AC mini grid. For households with low income and / or low energy consumption, DC solar home systems, pico systems or portable lamps are more suitable and can accompany in parallel a village electrification.

The target group of the AC mini grid is not people in the TIER 0, 1 or 2, but small businesses or agricultural activities above the TIER 3 group.

Simulation results

PV System	
PV Generator Output	30 kWp
Spec. Annual Yield	1741 kWh/kWp
PV Array Energy (AC Network)	50422 kWh/year
Stand-by Consumption	28 kWh/year
Performance Ratio	73,0 %
Consumer	
Consumption	37102 kWh/year
Battery	
Calculated Service Life of Batteries Cluster 1	9,9 years
Cycle Load Cluster 1	10,1 %
Total System	
System Efficiency	71,0 %
System Losses	13320 kWh
Solar Fraction	100,0 %

Figure 22: PV system sizing simulation results
Source: SMA off grid configurator, RAACH SOLAR

4.3 Price break down

A rough overview on the needed components of the PV system has been given in chapter 3.3.1. This chapter will give the bill of material needed to set up an AC mini grid in a village with 1000 inhabitants. The investment cost will reflect the prices of a photovoltaic system integrator (EPC company) including shipping cost to Niger, transport to site and installation services. The price will not include import duties, taxes and VAT.

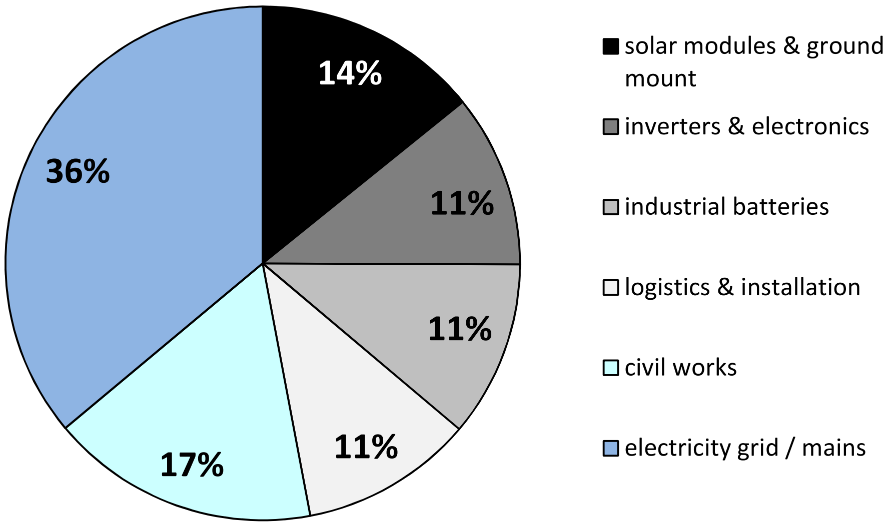

Figure 23: price break down of a 30kWp AC mini grid
Source: RAACH SOLAR

Figure 23 shows the price break down of a photovoltaic mini grid system with a 2km grid running through a village to supply the major subscribers. The price driver is mainly the infrastructure of civil works and grid expansion which represents nearly 50% of the total investment cost. The battery capacity was designed the way that the lifetime of the battery at 50% daily depth of discharge will last for more than 10 years under the hot ambient temperatures of Niger. All the other components are designed for a 20 years lifetime operation.

PRICE BREAK DOWN OF A 30kWp AC MINI GRID SYSTEM

SOLAR GENERATOR	UNITS	PRICE / UNIT	SUBTOTAL
solar generator 30kWp	1	21.045,00 €	21.045,00 €
on ground solar module support	1	5.520,00 €	5.520,00 €
DC combiner boxes	2	402,50 €	805,00 €
solar cables 1 x 6mm²	1000	0,81 €	805,00 €
solar cables 1 x 16mm²	200	2,07 €	414,00 €
accessories	1	552,00 €	552,00 €
INVERTERS & BATTERY			
grid tie inverter 15kW	2	2.932,50 €	5.865,00 €
AC combiner box	1	2.185,00 €	2.185,00 €
Inverter chargers 6kW	3	3.001,50 €	9.004,50 €
battery fuse	1	747,50 €	747,50 €
Industrial battery 48V-5000Ah	1	22.080,00 €	22.080,00 €
AC control box (60kW)	1	3.260,25 €	3.260,25 €
remote monitoring data logger	1	966,00 €	966,00 €
cables & accessories	1	1.104,00 €	1.104,00 €
SERVICES			
international transport & transport to site	1	12.017,50 €	12.017,50 €
installation of solar system	1	10.350,00 €	10.350,00 €
CIVIL WORKS			
operation building for batteries & inverters	1	16.700,00 €	16.700,00 €
concrete foundations for ground mount	1	11.000,00 €	11.000,00 €
security fence and gate	100	70,00 €	7.000,00 €
AC DISTRIBUTION GRID (2km)			
AC sub distribution cubicle (60kW)	1	3.358,00 €	3.358,00 €
three phase cable, isolators, poles	2	25.300,00 €	50.600,00 €
energy metering boards / prepayment	50	322,00 €	16.100,00 €
installation services	1	4.117,00 €	4.117,00 €
		TOTAL	**205.596 €**

Figure 24: detailed price break down of a 30kWp AC mini grid
Source: RAACH SOLAR

Figure 24 shows the details of the price break down by components. The overall price of a 30kWp AC mini grid is close to 205.000€, the price of the photovoltaic system is 100.000€. A large portion of the overall project costs is related to the electric grid infrastructure (36%) and civil works (17%).

What are now the production costs of electricity of the photovoltaic AC mini grid if we only consider the generator and not the civil works and not the electric grid? Because if we compare electricity production costs between photovoltaic systems and e.g. diesel generators, the electric grid is also not taken into consideration.

4.5 Electricity production cost

First there is a need to define the investment period which should correlate with the lifetime of an AC mini grid system. A 25 years lifetime of the in figure 23 listed components show certainly the infrastructure with the electric grid, shelter building and solar modules. Most of the manufacturers of solar modules give a 25% performance warranty of 80% of the nominal rated power. About 30% of the total investment cost and 60% of the PV system cost are the inverters and batteries whose lifetime should be estimated at 10 years.

The annual maintenance cost of the PV system including remote monitoring should not exceed 1% of the total PV system cost, which is equal to around 960€ / year. In a 10 years investment period, the total maintenance cost is estimated at 9600€.

The average yearly electricity production of the PV system is between 1741/kWp, but the distributed electricity is 37.102kWh. The 30kWp photovoltaic system will distribute in 10 years 371.020kWh.

The total investment cost without infrastructure is 96.720€ plus the 9.600€ maintenance cost = 106.320€. The method which is used to calculate the yearly cost of the investment is the annuity method which results in the capital service factor, the money which is needed to pay back the investment including the imputed interest. A 2% financial low interest rate is applied.

$$Kd = (Ao) \times [i(1+i)^n] / [(1+i)^n-1]$$

Kd = capital service

Ao = initial investment cost

I = P/100 interest rate

n = utilisation period

$$Kd = 106.320 \text{ Euro} \times [0,02\ (1+0,02)^{10}] / [(1+0,02)^{10} -1]$$

$$Kd = 11.836 \text{ Euro}$$

If the investment in a photovoltaic AC mini grid is 11.836 € per year, the PV system will be paid back within a period of 10 years. The total spending is consequently 10 years x 11.836€ = 111.836€. During this 10 years period, the PV system will have distributed 371.020kWh. The electricity price is calculated by dividing the total spending of 111.836€ by 371.020kWh = 0,3014€ / kWh. The production cost of electricity from the battery based AC mini grid is **0,30€ per kWh = 196 FCFA**.

If the construction of the mains and civil works is included in the economic analysis, the project cost in 10 years will be 205.596€ + 9.600€ maintenance cost = 215.196 €.

$$Kd = 215.196 \text{ Euro} \times [0{,}02\,(1+0{,}02)^{10}] / [(1+0{,}02)^{10} - 1]$$

$$Kd = 23.957 \text{ Euro}$$

If the total cost of the AC min-grid project is 23.957 x 10 years = 239.570€, the electricity production and distribution cost will be **0,6457 € / kWh = 422 FCFA**.

Even with a subsidy of around 60% of the total product budget for the construction of the AC grid and civil works, the price of electricity has to be 169 FCFA /KWh to operate the AC mini grid on a commercial basis. This is more than double the electricity price of 80FCFA, which the Nigelec customers have to pay in urban areas.

If a AC mini grid in rural areas is compared to the subsidized electricity prices in Niamey, a subsidy of 81% would be necessary to make it equal.

4.5 Financial analysis of DC solar home systems

Figure 25 shows a layout of a typical DC solar home system in which all components are cabled on a 12V DC line. The loads such as LED or CFL lights, radios, TV must have a 12VDC power supply. In our case, the solar home system is rated above the category of pico systems and comes with a 50Wp solar module, 12V/10A solar charge controller and a 12V 100Ah (C10) high class gel battery with 5 days autonomy. The lifetime of the components are designed for a minimum 10 years lifetime.

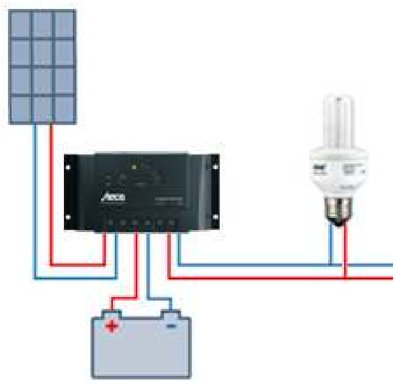

Figure 25: DC solar home system layout
Source: STECA

The gel battery is designed to last 10 years in hot ambient temperatures with an average depth of discharge of 20% per day (7500 cycles) which increases the investment cost but lowers the lifetime cost for the financial analysis. To respect international standards for safety, the battery is put into a box against touching and mechanical shocks.

PRICE BREAK DOWN OF A 50Wp SOLAR HOME SYSTEM

SOLAR GENERATOR	UNITS	PRICE / UNIT	SUBTOTAL
solar module 50Wp	1	40,25 €	40,25 €
solar module roof support	1	17,25 €	17,25 €
solar cables 1 x 6mm²	20	0,81 €	16,10 €
solar cables 1 x 16mm²	6	2,07 €	12,42 €
accessories	1	11,50 €	11,50 €
CHARGE CONTROLLER			
charge controller 12V/10A	1	20,70 €	20,70 €
BATTERY			
battery fuse	1	17,25 €	17,25 €
battery 12V-140Ah	1	299,00 €	299,00 €
battery box	1	46,00 €	46,00 €
LOADS & ACCESSORIES			
DC-Lamp LED, 12VDC-3W	4	8,05 €	32,20 €
DC-socket (TV / radio)	1	5,75 €	5,75 €
DC-switch	4	6,90 €	27,60 €
cable 2 x 4mm²	30	0,69 €	20,70 €
cable tube channel	30	1,38 €	41,40 €
SERVICES			
international transport & transport to site	1	48,05 €	48,05 €
installation of solar system	1	46,00 €	46,00 €
		TOTAL	**702 €**

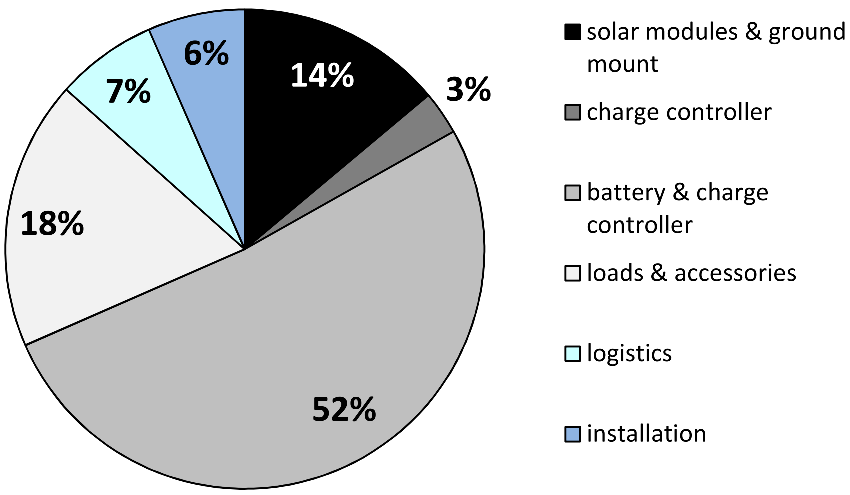

Figure 26: price break down of a 50Wp DC SOLAR HOME SYSTEM
Source: RAACH SOLAR

Figure 26 shows a price break down of the 50Wp DC solar home system with a minimum lifetime of 10 years. Because of the industrial battery quality, the battery and its security environment make up for more than 50% of the total investment cost. The price is calculated for a project size of minimum 100 systems.

The question is now, how much electricity is produced from the DC solar home system? After the software simulation by *NSOL* with the irradiation data of Niamey, the average electricity consumption per day of the load is 150Wh as shown in figure 27. The nighttime use is estimated at 50%. In one year the average distributed electricity to the load is 150Wh x 365days = 54,75kWh.

	Array	Avg	Array	Load	Night	Sys	Batt	ALR
Mont	kWh/m2	DegC	Ah/Day	Ah/Day	Load %	Loss %	Days	
Jan	6,11	24,6	15,1	11,9	50	10	6,71	1,27
Feb	6,04	27,0	14,9	11,9	50	10	6,72	1,26
Mar	6,02	31,0	14,9	11,9	50	10	6,72	1,25
Apr	5,54	33,5	13,7	11,9	50	10	6,72	1,15
May	5,60	33,3	13,9	11,9	50	10	6,72	1,16
Jun	5,23	30,8	13,0	11,9	50	10	6,72	1,09
Jul	5,27	28,2	13,0	11,9	50	10	6,72	1,10
Aug	4,97	26,7	12,3	11,9	50	10	6,72	1,03
Sep	5,47	28,0	13,5	11,9	50	10	6,72	1,14
Oct	5,98	30,0	14,8	11,9	50	10	6,72	1,24
Nov	5,98	28,0	14,8	11,9	50	10	6,72	1,24
Dec	5,69	25,9	14,1	11,9	50	10	6,72	1,18

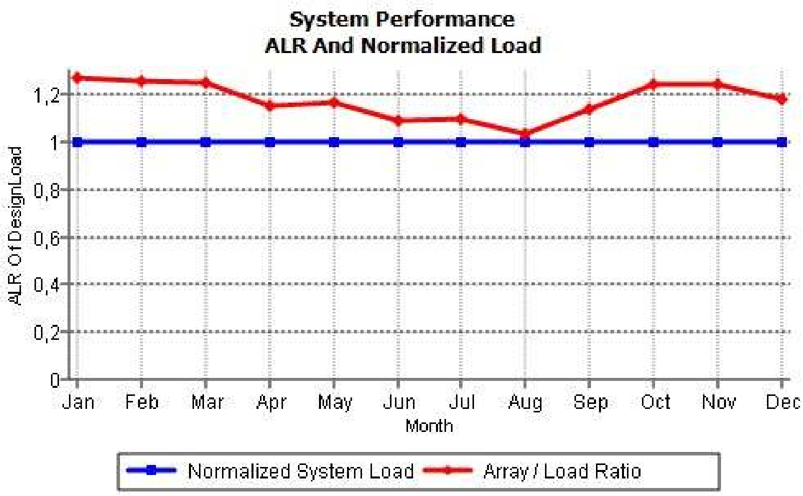

Figure 27: SHS software simulation
source: NSOL, RAACH SOLAR

The maintenance of the DC solar home system is nearly zero as the battery does not need to be exchanged or maintained, the solar module is cleaned by the owner. 1% maintenance cost are taken into account. The total cost of the DC SHS will be 702€ + 70€ = 772€ over an investment period of 10 years.

Kd = 772 Euro x $[0{,}02\ (1+0{,}02)^{10}]\ /\ [(1+0{,}02)^{10} -1]$

Kd = 85,94 Euro

The investment into a 50Wp DC solar home system costs annually 85 Euro against an electricity production of 54,75kWh per year. The distributed electricity price for a DC SHS is consequently 85,94Euro/54,75kWh = 1,64€ / kWh.

The advantage for solar home system is the low investment cost for a low energy consumption of a rural household of 702€ per household as shown in our example. The investment cost of an AC mini grid per household is more than double. In our example it is a minimum of 205.596€/125households = 1644€ per rural household.

5. CASE STUDY

5.1 visit of village Bossey Bangoue

A site visit of the none electrified village Bossey Bangoue situated close to the capital Niamey was carried out by SNV & RAACH SOLAR in November 2013 to learn more about the energy situation and income distribution in a rural area. The village elder Mr. Soumana Karmaize as shown on the front picture of this report was interviewed.[28] During the interview the teacher and other important village personalities came to join the discussions.

The village has 973 inhabitants according to the last population census in 2011 which corresponds to around 100 households. The major activities and professions are religious teaching, farming, gardening. The village suffers from rural exodus of the young people but they stay connected to the village. There is a mosque, 3 shop, school and a health center. The village recently got a manual borehole pump.

The village was not electrified and the first questions wanted to find out how the energy situation looks like in the village without electricity. Lighting is the major application and concern of all households. Most of the households have LED lamps (2000CFA) and radios (5000CFA) for entertainment which run on batteries. The village also has 12 small fuel generators “HITACHI” and 20 motor pumps for irrigation in different places.

What does the village currently spend for electricity? The owners of LED torches or lamps spend around 500 CFA / week for mainly MIGNON AA batteries, the fuel generators cost 1000 to 2000FCFA per day. Many people own mobile phones and charge them for 100 CFA per day.

Overview of current estimated electricity expenditure

Appliance	Quantity	cost/ week	Subtotal / week
LED torches / lamp	100	500 CFA (0,76€)	76,00€
Phone charging	100	700 CFA (1,07€)	107,00€
Fuel generators	12	5000 CFA (7,60€)	91,20€
		spending per week (estimated)	274,20€
		spending per year (estimated)	13.710,00€

Roughly calculated, the every inhabitant spends 14€ per year for electricity services, which is around 112€ per household and year.

What are the major income sources of the village? The teacher said he earns money from Koran teaching. Mr. Karmaize said that his sons work in the Ivory Coast and sent regularly money home to the village. This family situation seemed to be common for the village. Some farmers raise animals and sell it on the market. The major income source seemed to be agricultural activities, cultivation of

[28] Interview by Mr. Kelley, dated 29.11.2013

vegetables and selling them on the market. There are only a view sales persons who sell other products for the daily life needs.

It was very difficult to work out an income pattern in the village and it was discussed with the village people. People were considered as rich when they spent more between 20000 CFA (30€) per month for energy services. The teacher estimated these people at around 10%. The middle income group (30%) was estimated at around 5.000CFA (15 €) per month and the average (poor) at around 2000 CFA (3 €) per month.

How would the situation improve if the village had electricity? The first spontaneous reaction was the desire for a freezer to make and sell ice, an electric mill to grind wheat, a fridge to store medicine, yoghurt and milk, electricity to reduce fuel spending for the irrigation pumps and there is a need for a welder.

In summary, the villagers already spend money for basic electricity services which can be harvested to co-finance an AC mini grid. Solar power has not been used yet and the motivation is high to use electric power for productive use to increase the income and comfort of the village.

5.2 visit of village Gorou Beri

The interview in the village of Gorou Beri was given by the village chief Mr. Mounkaila Moussa. The village of Gorou Beri is also not yet electrified and is situated in the larger outskirts of Niamey. The village is divided into 6 groups of houses and has in total 864 inhabitants which are approximately 80 households. The village is close to an open watering place.

Main income source is farming, especially vegetables and stock-breeding. There is one shop per hamlet where people can buy batteries. Most of the people stay and work in the village, only 10 people go to Niamey to work.

The current electricity demand is driven by the lighting, mobile phone charging and as well electric pumps for agricultural irrigation. The village also has a mill which runs on a diesel generator and uses 5 liter diesel every day which amounts for 4 € / day. The grinding service of a 2kg flour bowl costs between 35 and 50CFA (0,08€). The diesel price in Niger is currently at 540 CFA / liter (0.82€). Villagers sometimes take loans to buy diesel fuel. There are already 10 motor pumps in this hamlet which is the closest to the watering place. Mr. Mounkaila said that 20 households of the hamlet with 30 households could afford to pay 3000 to 4000 CFA per month on electricity (6 €).

Overview of current estimated electricity expenditure

Appliance	Quantity	cost/ week	Subtotal / week
LED torches / lamp	80	500 CFA (0,76€)	76,00€
Phone charging	80	700 CFA (1,07€)	107,00€
Electric Mill	1	2700 CFA (20,61€)	20,61€
Fuel generators	15	6000 CFA (9,16€)	137,40€
		spending per week (estimated)	341,01€
		spending per year (estimated)	17.050,50€

The future electricity demand is driven by the desire to have fans, televisions and the possibility to charge mobile phones.

5.3 Pricing strategy for AC mini grids

AC mini grids deliver standard 1 x 230VAC or 3 x 400VAC alternating current to the customers and standard AC energy meters seem to be at first sight the most appropriate mean to bill kWh. The financial analysis has shown in chapter 4.4 that the break-even price for a commercial operator has to be minimum 0,65€ / kWh. But there will be low *willingness to pay* electricity at this rate from the rural population when they see their counterparts in urban Niamey to pay only a subsidized price of 0,12€/kWh. What the rural population does not see is that they already pay almost 1€ /kWh for small diesel generators which run their irrigation pumps and 2 to 3€ /kWh for mobile phone charging services or batteries for their torches.

Under pure market conditions, a 30kWp AC mini grid will cost 23.957€ annually as shown in chapter 4.4 and can supply a village with around 1000 inhabitants. The cost of financial management and risk assessment not yet included. A careful estimation of the *capability to pay* of a typical village close to Niamey is between 13.000€ and 17.000€ annually. The project will not be sustainable without start up subsidy of minimum 60% of the project value.

Like selling batteries for torches and not kWh, like selling diesel fuel for motor pumps and not kWh, AC mini grids have to sell their services and not kWh.

In a 30kWp PV system, there are available 100kWh per day as distributed electricity power, which can be classified in three consumption levels:

1. Productive use for all commercial activities which should be the driving force of the village to increase the overall income. About 50% of the electricity consumption should go into these activities.
2. Private consumption mainly for lighting, mobile phone charging and information by radio or small scale TV. Not more than 35% of the village electricity consumption should go into these activities.
3. Community services which cannot be contributed to a single consumer should make up not for more than 15% of the total consumption. All the village community will profit from these services such as public street lighting, health care and school.

Figure 28 shows the estimated electricity consumption of an average 1000 inhabitants' village in Niger which consists of an average 125 households. About 50 single subscribers are identified, which also means, that not all households will benefit directly from the AC mini grid. The ones who cannot afford an immediate subscription, will benefit indirectly from the community services and the increasing commercial activities. The consumption level 1 are the subscribers which already have a regular income through agricultural, craftsmanship's or commercial activities and might consume 4kWh or more per day. The consumption level 2 are private households which consume between 1 and 2kWh / day mainly for lighting and information purposes. Consumption level 3 envelop all community services not exceeding a consumption of 2kWh / day.

CONSUMPTION LEVEL 1 = 4kWh / day (PRODUCTIVE USE)					
designation	application	quantity [units]	rating [kw]	hours [h]	consumption [kWh]
motor pump	irrigation	10	1,5	2,5	37,5
shops	lighting & refrigeration	3	0,5	6	9
welder	welding of iron	1	4	1	4
				SUBTOTAL 1	50,5
CONSUMPTION LEVEL 2 = 2kWh / day (PRIVATE CONSUMPTION)					
designation	application	quantity [units]	rating [kw]	hours [h]	consumption [kWh]
major / village elder	lighting & information	1	0,5	4	2
koran teacher	lighting & information	1	0,5	4	2
school teacher	lighting & information	1	0,5	4	2
households	lighting & information	27	0,25	4	27
				SUBTOTAL 2	33
CONSUMPTION LEVEL 3 = 2kWh / day (COMMUNITY SERVICES)					
designation	application	quantity [units]	rating [kw]	hours [h]	consumption [kWh]
streetlight	lighting 36W	4	0,36	6	8,64
health center	lighting & vaccine storage	1	0,5	4	2
school	lighting & information	1	0,5	4	2
		50		SUBTOTAL 3	12,64
				TOTAL CONSUMPTION PER DAY [kWh]	**96,14**

Figure 28: definition of energy consumption levels
source: RAACH SOLAR

CONSUMPTION LEVEL 1 = 6kWh / day (PRODUCTIVE USE)				
designation	application	quantity [units]	subscription	monthly expenditure
motor pump	irrigation	10	35,00 €	350,00 €
shops	lighting & refrigeration	3	35,00 €	105,00 €
welder	welding of iron	1	35,00 €	35,00 €
			SUBTOTAL 1	490,00 €
CONSUMPTION LEVEL 2 = 2kWh / day (PRIVATE CONSUMPTION)				
designation	application	quantity [units]	subscription	monthly expenditure
major / village elder	lighting & information	1	20,00 €	20,00 €
koran teacher	lighting & information	1	20,00 €	20,00 €
school teacher	lighting & information	1	20,00 €	20,00 €
households	lighting & information	27	20,00 €	540,00 €
			SUBTOTAL 2	600,00 €
CONSUMPTION LEVEL 3 = 2kWh / day (COMMUNITY SERVICES)				
designation	application	quantity [units]	subscription	monthly expenditure
streetlight	lighting 36W	4	20,00 €	80,00 €
health center	lighting & vaccine storage	1	20,00 €	20,00 €
school	lighting & information	1	20,00 €	20,00 €
			SUBTOTAL 3	120,00 €
			TOTAL REVENUE PER MONTH	**1.210,00 €**
			TOTAL REVENUE PER YEAR	**14.520,00 €**

Figure 29: estimated monthly and annual revenues
source: RAACH SOLAR

Figure 29 shows the estimated revenue from electricity sales in the AC mini grid system based on monthly fixed lump sum subscription for the different consumption levels:

1. consumption level = 25.000 CFA (35€) = 0,29€ / kWh
2. consumption level = 15.000 CFA (20€) = 0,33€ / kWh
3. consumption level = 15.000 CFA (20€) = 0,33€ / kWh

The monthly payments correspond approximately to the capability to pay as worked out in chapter 5.1 and chapter 5.2, but will not cover the real cost of the AC mini grid investment as shown in chapter 4.4 of 23.957€ per year.

5.4 Prepayment meters and load management

In Senegal, the Agency for Rural Electrification ASER has defined four different consumption levels for rural electrification and also limits the maximum power consumption.[29]

Consumption level	Monthly payments	Maximum power
Level N1	4000 CFA (6,10€)	50W
Level N2	7500 CFA (11,45€)	65W
Level N3	13000 CFA (19,84€)	180W
Level N4	120CFA / kWh (0,18€/kWh)	>180W

In different AC mini grid projects in Senegal, the private operators can ask higher monthly lump sum payments for a grid connection and can consequently hide the real FCFA per kWh price. The disadvantage of lump sum payments is that the subscribers can buy more electric loads such as fridges, irons, HIFI equipment as allowed and can consume whatever he wishes. The pure availability of electricity for households and the sudden increase of connected power by more electric appliances and increased consumption has lead in the past for a collapse of many AC mini grid projects.

Every AC mini grid needs to have an intelligent power and consumption management to which is also refered to as “load profile management”. Every subscriber needs to be limited in power [W] and consumption [Wh]. But how can it be avoided that a subscriber will not use more kWh per day as allocated?

“The energy dispenser function is based on the patented concept of the daily energy allowance, allowing the user a smart management of the available electricity in grids with limited or pulsating generation, such as those fed with renewable energy sources.
It includes a main switch that works as a maximum power and maximum demand control as well as an auxiliary switch that can be used for connection or disconnection of non-essential consumptions.
The energy meter complies with the European regulations (MID) EN 50470-1 and EN50470-3, being class B for active energy measuring and class 2 for reactive energy measuring.
It has a standard optical port and a communications port for network connection used for the writing/reading of parameters and for data logging.

[29] Source:ASER, Senegal 2014

It incorporates a wireless RFID card reader were the configuration parameters, according to the grid where it will be connected, are included, and also used as a contract and billing control. The LCD screen and LEDs enable the user to check the energy availability."[30]

Intelligent load management is necessary to distribute the electric consumers especially for productive use (pumps, welding machine etc) equally over the daytime and reduce the peak load in the evening to safe battery capacity and extend the battery lifetime.

But energy dispensers also offer so called "prepayment services". The term *prepayment* has several definitions, but a very common an good one is "*Prepayments* are amounts paid for by the business in advance of the goods or services being received at the period or year end".[31] In the context of AC mini grids, the subscriber pays the electricity bill in advance before he consumes. He always pays in advance and when the credit is over, the prepayment energy meter will cut off his electric loads.

In many small scale SHS projects it is difficult and expensive to collect the monthly payments from the solar home system user. If prepayment technology is used, the subscriber has to come to a selling point where he gets a new code for his prepayment energy meter or he recharges his card or electronic memory chip. When he comes back to his house he either enters the new code by a keypad into the meter or he puts the electronic key, card or chip into a slot. Some new technological approaches have been made by transferring credits from prepaid mobile phones to electricity companies to get in return the activation code.

The prepayment technology reduces the cost of manual money collection, but some say it is the opposite because expensive technology is needed and a central management point with computer and software. There is a risk of theft if the money from the subscribers of AC mini grids is collected manually. The sums are not 500 to 1000 CFA, there is 5000 to 20000 CFA to collect with every customer. Every financial transaction is recorded, payments and non-payments are registered, frequency of payments and cash flow is analyzed.

The prepayment technology does not only offer a better financial risk management, it also offers to the project operator detailed technical information about load profile and the overall condition of the photovoltaic system. Every time the subscriber recharges his credit at the pay station, technical data is transmitted as well to the computer. The project operator can better plan its after sales service intervals.

The prepayment energy meter should also offer flexible credit management. One principle should be that a household is not punished if there is one or two days no electricity consumption and the electricity credit should be accumulated of up to 3 days of electricity credit (e.g. 3 x 4kwh = 12kWh), e.g. he is allowed to consumer in one day double or triple his usual consumption. If for any reason the household cannot recharge its credit at the end of the prepayment period, a maximum of 2 days grace period should be granted.

[30] Circutor data sheet, provided by Trama TecnoAmbiental (TTA)
[31] www.e-conomic.co.uk

5.5 Identification and definition of the roles of actors

One lesson learnt from the past AC mini grid projects is to avoid conflicts of interest. Compliance is the key word which says that the roles of each involved party needs to be defined and each party has to respect ethically correct the rules to maintain the order and discipline. For example the son of the village elder cannot work for the company who takes care of technical after sales service, otherwise the risk is there, that a fake technical defect can be constructed to give work and payments for the SAV company.

There are several options to set up an efficient organization to run AC-mini grids successfully. The ARE distinguishes four different models:[32]

1. community based model
2. private sector based model
3. utility based model
4. hybrid business model

Our approach is limited to a pure photovoltaic AC mini grid as the villages targeted in this study have no supply to constant water flows for hydro hybrid systems and it is also assumed in this study that the electricity prices for diesel systems are superior to PV stand alone systems. The typical diesel consumption of a 10kVA generator is 1liter = 3 to 4kWh. Only the fuel will cost an electricity price between 160 and 200 FCFA (>0.25€) per kWh.

In the community bases model, the ownership and management is in the hands of the village community. There are many disadvantages linked to this model, as there are too many political interests. For example: the families who are close to the village elder and community will always get preferential attendance than the ones who are not part of the ruling party. Where ever money can be earned in the technical after sales service or money collection, there will be always conflicts of interest.

In the utility based model, the national utility company will own and manage the AC mini grid as part of the public interest in rural electrification. NIGELEC is already expanding in rural areas also thanks to international funding, but as a private profit orientated organization, rural electrification by grid extension at subsidized electricity prices is always in short term a financial loss to the power company.

The hybrid business model combines advantages of several different models. The ownership of e.g. the grid is separated from the ownership of the power generation. A utility can team up with a regional service partner. The utility can set up the AC mini grid and sells electricity to a fixed price. The distribution and sales of electricity is in the hands of a local service company which manages the revenue collection and after sales service. But also in this business model, the profitability is a critical issue.

The private sector based model is in this study the favorite model. The ownership remains in the hands of a private company who runs the AC mini grid project under commercial profit orientated

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parameters based on a business plan. If the rural population cannot afford the commercial electricity prices, the private company can enter into a public private partnership. The public interest in electrifying the rural population and in increasing their productivity and income marries with the private company's interest in running a profitable sustainable business.

Government

In Niger's electricity code the monopoly of energy production and distribution is in the hands of the Ministry of Energy respectively NIGELEC. If a private company or another organization wants to electrify a village, it needs the permission of the government which allocates a limited right to electrify a certain area on private initiative. The Ministry normally delegates these decisions to a half governmental organization which is called Rural Electrification Agency. This agency must coordinate the electrification tariffs and electrification plans between private operators and NIGELEC. The private operator needs to sign an agreement with the rural electrification agency.

Quality Control / consultant

The correct sizing of the PV system to the village, the quality of components and specifications need to be controlled before delivery, before installation, during installation and at the moment of commissioning. Not the lowest investment cost, but the lowest lifecycle cost is important for the sustainability of the project. This company is typically a consultant or a quality control company.

Supplier

The supplier of an AC mini grid will engineer, procure, deliver and commission the AC mini grid. This company can be an EPC, a system integrator or an electricity company. The supplier will deliver the PV system as a turn-key solution including the AC grid. As soon as the mini grid is installed, his job is done and the payments are received. He needs to get new contracts to sustain his business. He guarantees the delivered components over a fixed warranty period which is normally between 2 and 5 years. He is only active when he receives an official warranty claim and changes components. After commissioning of the PV system, the ownership is transferred to the owner.

After the warranty period he can quote replacement components or a possible extension of the mini grid when the electricity demand side increases.

Owner of the AC mini grid / RESCO

The owner of the AC mini grid has the interest to maintain the photovoltaic system in its best condition and to profit from the hidden reserves when the system will be paid off after a period of 10 years and will still work. When his business is profitable, he is interested in expanding the PV systems capacity or install new PV systems in other villages.

The owner is typically a NGO, a private company, an electricity company, investor or energy service company. In some countries the owner is a "concession holder", e.g. a company which gets from the government an exclusive right, limited in time, to electrify a certain region of a country. The owner should not be linked to the village to prevent conflict of interests. It should not be the village community or persons from the village.

The experiences with an owner of a state owned company such as Ministry of Energy or Ministry of Water have not been positive in the past. In most of the cases there is low maintenance due to lack of financial resources.

The ownership of the AC mini grid will not be transferred to the village community. The subscriber cannot be the owner.

NGO

The village community should be involved from the very beginning. Typically a NGO informs the village committee about the planned electrification and prepares an information campaign for the whole village. The NGO works out how many potential subscribers have the capability to pay and how many different consumption levels there are in the village. This results in a list of potential subscribers. The NGO will carry out an awareness campaign on electricity use (health and safety plan) and energy consumption. Even after the official inauguration of the AC mini grid system, the NGO can accompany the use of the AC mini grid by a social economic study. The NGO can also get involved in future expansion of the AC mini grid.

Village community

The village community is headed by the village elder or major and involves particular outstanding persons who are elected by the majority of the villagers or nominated by their profession or religion. The village community allocates a free land to set up the operation building for the batteries and inverters for the RESCO and will sign a land usage and operations contract with the RESCO. The contract also defines possible penalties if electricity is stolen, none respect of payments or technical defects of the mini grid occur.

The village community is as well a customer to the RESCO. It pays for electricity of the community services such as street lighting, school and health center. It is also an organization community and central contact person for the daily management of the AC mini grid. The village community designates one person who is the contact person giving alert of possible system break downs to the RESCO. This person can also be trained by the RESCO or the after sales service company to manage and repair simple defects or read out error messages on the inverter displays.

Household

The households are one of the most important customer groups in a AC mini grid. It is defined as the smallest possible customer per unit. Thanks to an electricity connection a household can develop to a productive user with higher energy demand by increasing commercial or craftsmanship activity. A household is equipped with an energy prepayment meter and pays a monthly lump sum fee for his energy consumption level.

Technical after sales service

The after sales service is in the responsibility of the owner of the AC mini grid. The RESCO can do it by itself or subcontract theses services to a technically specialized electric company. This also can be NIGELEC or the affiliate / partner of the original supplier (EPC). The technical after sales services must be regulated in a contract and as well the pricing of the individual services to prevent abuse or fake missions to site.

Financial management

The owner of the AC mini grid is the party who finances the operations either takes a credit at the bank or finances the PV system by his own investment. This investment need to be paid back.

If prepayment meters are used there is a central computer based payment station in Niamey or the next larger easy accessible sales point. The subscribers come on a monthly basis to recharge their credits. The owner of the AC mini grid gets monthly financial and technical data from the AC mini grid. The financial feed-back on frequency of payments and total amounts allows him to plan the installments to pay back its credit at the bank. The financial management could be done by banks but the active money collection is not their motivation. MFI can play here an active role in consulting and money collection, but whoever will take this responsibility needs to be paid for.

The technical data can be shared with the after sales service company which can better plan and reduce service intervals. The data allow the owner to control the necessity and timing of after sales service missions.

The financial data can be shared with financing banks or in private public partnership with international donors.

The MFI can also accompany the rural electrification projects e.g. by giving micro credits to farmers for electric pumps and seeds who want to increase productivity.

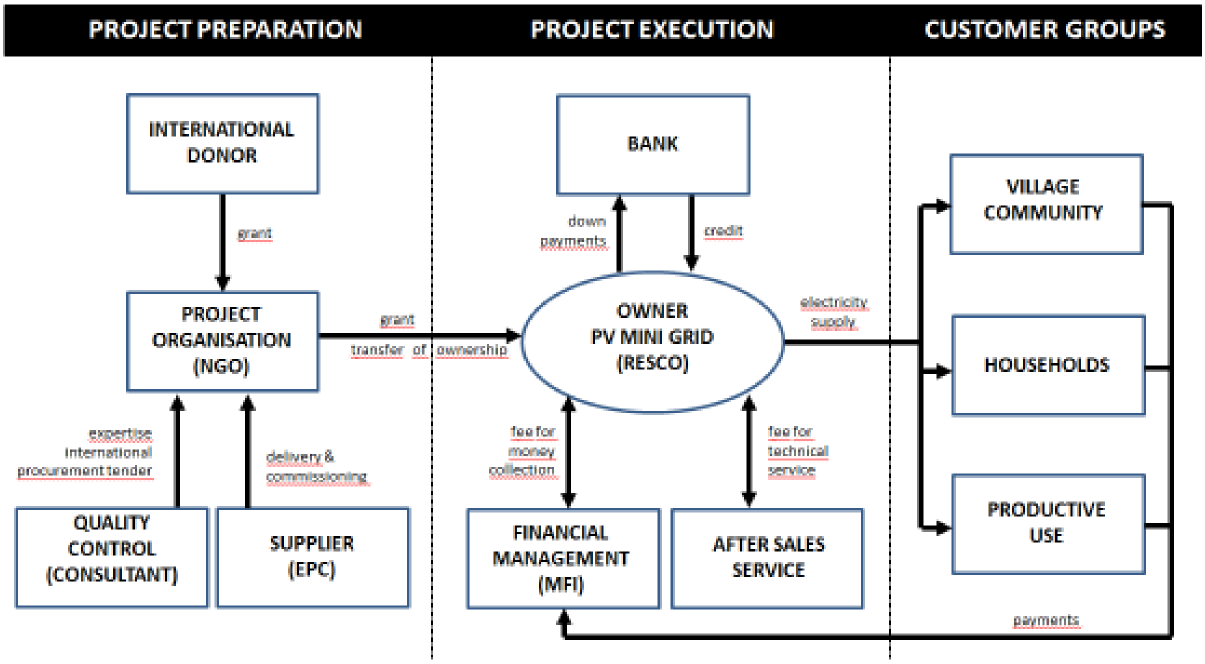

Figure 30: AC mini grid project organization
source: RAACH SOLAR

6. SIMULATION AND RESULTS

6.1 Analysis of risks for project execution

The different actors were analyzed in chapter 5 and for every actor there are risks involved in the project financing and execution. The risk analysis is concentrated on the owner of AC-mini grid, because he will bear the financial and technical risks during the lifetime of the project.

NATURE OF RISK	COUNTER MEASURES	FINANCIAL EVALUATION
POLITICAL RISKS		
political unrest, vandalism, looting, general strike	selection of lower risk regions	*force majeure*
war, destruction of PV system and components	selection of lower risk regions	*force majeure*
abandonment of village, poverty, refugees	selection of lower risk regions with lower ethical conflicts	*force majeure*
Nationalization of energy supply	selection of lower risk regions dedicated to free market economy	*force majeure*
LEGAL RISKS		
change of law to reduce electricity tariffs by force	at beginning of project the electricity tariffs should be approved the national electricity company; sign a contract under a special regime for rural electrification with international donor; if possible sign contract covered under a different law (e.g. CIGS)	low risk
Reestablishment of energy monopoly by a state owned company, expropriation	negotiate an adequate sales price of PV system if possible	*force majeure*
Unsolved land property rights due to lack of cadaster	the use of land by PV system must be negotiated with the village and a land use contract needs to be sign by the village and RESCO before project start	low risk; village will lend land for free because interest in electrification is higher
claim for damages from villagers because electricity injured or killed people	1) Respect all international safety standards 2) Quality control: select components only from approved suppliers 3) Prepare village for electrification and training on use of electricity; let them sign that they participated in the training	training of villagers: 5.000€ local health and safety plan: 1.000€ quality control: 20.000€ (tender documents; delivery of goods, commissioning of system by third party)

TECHNICAL RISKS		
break down & failure of components before end of lifetime	quality control; negotiate extension of warranties from manufacturer	quality control: tender documents; delivery of goods, commissioning of system by third party
No availability of spare parts or replacement products after warranty period	Select reputed manufacturers with good after sales service records Modulare design of PV system to allow the use of different manufacturers	See above "quality control"
too frequent after sales service operations	Identify source of failures; sign contracts with manufacturers to take over as well service costs and no only "EXW values"	See above "quality control"
new technical inventions fade out use of AC mini grids	New and cheaper technology will compete existing AC mini grids	*force majeure*
lack of acceptance by villagers who refuse new technology	Involve villagers by awareness campaign before electrification starts	training of villagers, awareness campaign: 20.000€
FINANCIAL RISKS		
lack of profitability: more cost than returns	1) select higher income villages 2) assess villagers capability to pay 3) analyze current electricity consumption 4) identify amount of subsidy needed to run project profitable	Consulting case study: 30.000€
unwillingness to pay of customers	1) start awareness campaign before electrification 2) update awareness and motivation to pay after 1 year and 2 years	Awareness creation update: 10.000€
withdrawal of credit line from bank	If RESCO takes a private credit to co-finance the project, risks of immediate payback must be limited by e.g. involving two banks and an international donor	Credit risk insurance: 500€ per year = 5.000€ over minimum project lifetime
no capability to pay from villagers due to bad harvest	try to make 3 months upfront payments per subscriber before project starts and keep it as caution to balance bad times	low risk, partially *force majeure*
theft of money from involved parties (e.g. MFI, after sales service company)	prevent conflict of interests to avoid unnecessary after sales service operations or money to paid back to the bank account; use technology such as prepayment meters to record	Cost of project management: 500€ per month, 6000€ per year and 60.000€ per 10 years

	payments and PV system availability	
village is electrified by public grid during project period	check national electrification plan before project start	Cost are covered by consulting study
theft and vandalism	Theft insurance, but can turn out to be expensive	Insurance see below
damages to house, goods and people during operation	comprehensive general liability insurance (CGL)	insurance: 1000€ per year (if available)
damage by transport & storage	1) include in tender already spare parts of major components 2) suppliers should deliver components including transport insurance	Transport insurance to site: 1% of goods value = 2000€
ENVIRONMENTAL RISKS		
pollution	No air, soil, noise pollution during project period; check recyclability of batteries in the project country	Low risk
climate change, desertification	will lead to increasing poverty and low capability to pay	*force majeure*
hurricanes, storms, hailstorms, lightning, floodings	1) select village in lower lightning and storm risk area 2) protect batteries & inverters by shelter 3) lightning and grounding concept of PV system 4) Will destroy photovoltaic modules, no protection possible	Additional lightning concept: 10.000€ natural hazard insurance: 500€ per year (if available)
lack of sunshine by unexceptional event (volcano etc)	design PV system in the way that it can be operated with an additional wind power or diesel generator	should be covered by consulting study

Figure 31: financial evaluation of project risks
source: RAACH SOLAR

In summary the risks can be split in three categories: the first category needs accompanying measures to increase acceptance and awareness, the second category can be covered by insurances and the third category is *force majeure*. To cover the additional risks of such a project, almost another 100.000€ are necessary. The more AC mini grids are involved in such a project, the lower the cost per project can be.

SUMMARY OF PROJECT RISKS CATEGORIES	**DESCRIPTION**	**FINANCIAL IMPACT (10 years)**
CATEGORY I	Accompanying measures	Training (safety): 5.000 € HSE plan: 1.000 € Consulting (tender): 20.000 € Training (Awareness): 20.000 € Consulting (finances): 30.000 € Subtotal 1: 76.000 €
CATEGORY II	Natural elementary risks	Insurance (credit risk): 5.000 € Insurance (CGL): 10.000 € Insurance (transport): 2.000 € Insurance (hazard): 5.000 € Subtotal 2: 22.000 €
CATEGORY III	*Force majeure* such as political unrest, revolution	*Partial or total loss of project*

Figure 32: summary of project risk categories
source: RAACH SOLAR

6.2 Set up of financial model

The overall cost of a AC mini grid pilot project comprehends the investment cost for the solar generator, the AC grid, the additional cost for the risk coverage, the cost of project management and the financial transaction cost for prepayment technology. In chapter 4.4 the investment cost were calculated to 205.000€, in chapter 6.1 the additional risk cost to another 98.000€ (10 years), the project management cost and the financial transaction costs of the operator to 60.000€ (10 years) .

Assumed that the project is made of 5 units AC mini grids, the total investment would be 5 x 205.000€ = 1.025.000€, adding maintenance cost (1% p.a.) of 5 x 9600€ = 48.000€. Assumed that the accompanying measures and insurance cost will be 50% off based on economies of scale, the extra cost would be 5 x 98.000€ / 2 = 245.000€. Assumed that the project management cost including the cost for the payment collection by using prepayment technology, would also profit from a more efficient management with only 2-3 payment collection points for 5 villages, the cost can be at 5 x 60.000€ /2 = 150.000€. The total project cost of 5 AC mini grids over a period of 10 years can be estimated at 1.468.000€.

What is the contribution of the villagers and their payments which are collected? In chapter 5.1 and chapter 5.2 the annual expense for electricity was calculated at average 14.000€ per village. Five villages would be able to pay 70.000€ per year or 700.000€ in 10 years.

6.3 Cash flow analysis

CASH FLOW PLAN WITHOUT SUBSIDY													
year 1	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEZ**	**Sub-total**
expenses													
hardware investment	1.025.000 €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	1.025.000 €
maintenance cost	400 €	400	400	400	400	400	400	400	400	400	400	400	4.800 €
Accompany-ing measures	2.040 €	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	24.480 €
managment cost	1.250 €	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	15.000 €
receipts													
sales electricity	5.850 €	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	70.200 €
CASH FLOW	-1.022.840 €	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	-999.080 €

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
CASH FLOW	-999.080 €	-973.160 €	-947.240 €	-921.320 €	-895.400 €	-869.480 €	-843.560 €	-817.640 €	-791.720 €	-765.800 €

Figure 33: cash flow overview without subsidies
source: RAACH SOLAR

Assumed there is a pilot project on five mini grids systems, the investment cost would be 1.025.000€ for the hardware and installation. The maintenance cost, the accompanying measures, the management cost will lead to further monthly expenses which will add to 1.069.280 € in the first year minus the earnings from the sales of electricity of 70.200€. The first year will end with a negative cash flow of 999.080€.

The investment period of 10 years will reduce the negative cash flow to -765.800€ by additional sales of electricity. However the cash flow will be still negative if there are no further price increases for electricity or a significant improvement of the income situation of the villagers.

The project is not sustainable if it is operated on a pure commercial basis.

The financial situation improves, if a subsidy of 60% on the total project cost is awarded or 80% on the hardware cost.

CASH FLOW PLAN WITH SUBSIDY (80% on hardware)													
year 1	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEZ**	**Sub-total**
expenses													
hardware investment	205.000 €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	205.000 €
maintenance cost	400	400	400	400	400	400	400	400	400	400	400	400	4.800 €
Accompany-ing measures	2.040 €	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	2.040	24.480 €
managment cost	1.250 €	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	15.000 €
receipts													
sales electricity	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	5.850	70.200
CASH FLOW	-202.840 €	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	2.160	-179.080 €

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
CASH FLOW	-179.080 €	-153.160 €	-127.240 €	-101.320 €	-75.400 €	-49.480 €	-23.560 €	**2.360 €**	**28.280 €**	**54.200 €**

Figure 34: cash flow overview with 60% subsidies
source: RAACH SOLAR

A subsidy of 80% on the hardware cost will reduce the initial expense to 205.000€ and the earnings from the sales of electricity will turn the negative cash flow into a positive cash flow between the eight and tenth year of operation.

In both calculations, the financial interest or the so called imputed interest were not considered. If the investment cost of 1.025.000€ has to yield interest, this would lead to another financial spending of 2% (=20.500€ / year) or of 6% for private consumer credits (=61.500€/ year) currently applied within the European Community. In the following years 2 to 10, the compounded interest (interest on interest) will worsen the situation.

$$K_n = K_0 * (1 + p)^n$$

If *Kn* is the capital after *n*-years, *K0* is the seed capital, *p* the interest rate and *n* the number of years. In our example, the seed capital would be 205.000€, 2% the credit interest and 10 years the investment period. After 10 years, the interest on the 205.000€ seed capital would be 249.893€ - 205.000€ = 44.893€. This confirms the assumption, that a 80% subsidy on the hardware would probably bring the project to break even in the 10th year.

7. CONCLUSIONS

The market research results have shown that most of the future photovoltaic capacity will be added in Niger as grid connected photovoltaic power plants and small and medium sized companies (SME) will not profit from the increasing market volume as long as the market segment of small and mediums sized private photovoltaic grid connected systems is not developed.

The large scale grid connected photovoltaic power plants will also not have an impact on rural electrification and the rural non electrified villages will not benefit from these power plants.

Market research has also shown that pico systems and DC solar home systems have an impact on improved living conditions of the rural population but have little effect on productive use such as AC water pumps, electric flour mills and craftsmen. There will be no development of the rural areas without increasing the income and productivity of the rural population by professional and clean electrification.

Solar home systems have one of the highest kWh electricity production cost and AC mini grids are more competitive. However the financial burden of risk assessment, electric grid and management cost compared to the real capability to pay makes a private investment which looks for profitability not attractive.

The financial model has shown that within a private public partnership and a upfront subsidy of 60% of the total project costs, respectively 80% of the hardware cost, the AC mini grid can break even after an investment period of 10 years, which is the estimated and simulated lifetime of the industrial solar battery before it comes to a plough-back.

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