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MEASURING THE SOCIAL WELFARE OF A SOLAR POWER PLANT IN WEST AFRICA - A SOCIAL RETURN ON INVESTMENT (SROI) MODEL

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Abstract

The purpose of the paper is to present an example for the electrification of rural Africa. We will discuss the preconditions, necessities and obstacles of building a solar power plant in rural Niger. For the energy supply of a small village in West Africa a solar pilot plant (20 kWp solar plant with battery storage) is installed. This energy hub makes it possible to provide solar-powered electricity for the town, operate a (ground) water pumping system-delivering water for households and for irrigation of fields. The aim of the paper is to determine the social and individual welfare effects of the new energy system. Therefore, the social well-being of the village is analysed by the social return on investment (ŁSROI) model. The analysis starts with an empirical survey of the households of the village. The villagers were asked to assess the benefits of the new solar power plant investment for their household and for the whole village. Investment and household valuation are intertemporal decisions whose consequences occur at different points in time, and social actors may have different time preferences. Therefore, two different discount methods are considered. The classical standard discounting model for the technical investment and the hyperbolic discounting for the discounting of the utility of the pilot plant for the households. Four different time preference rates (0%, 1%, 5%, 10%) are used to capture different risk assumptions caused by the current global and local risks (rising energy and food prices, corona pandemic, climate change, water scarcity) and defining thereby the social time preference space. The social return on investment model determines the social return on investment for the households of the village. By rising the time preference rate from 0% to 10% a significant decline of the social benefits of the solar pilot plant can be determined. The global and local risks will rise the time preference rate of the villagers because the present becomes more and more difficult to manage and the visible future is reduced. Hence, the social revenues of the pilot plant decrease over time.

Keywords:* *Welfare Economics, SROI, Energy, Investment Model, West Africa

1. INTRODUCTION

The purpose of this research is to analyse the options for providing decentralised energy systems in rural Niger. The paper examines the social return of investing in a solar power system in a small village in Niger, West Africa. The social return on investment approach has the advantage of providing a more comprehensive picture of the socio-economic impact of the solar power investment. The social rate of return model shows the close link between the time preference rate, which represents the social, economic and environmental pressures on village households, and the social rate of return of the investment. The focus of the research is only on rural West Africa, further research is necessary if the research method is to be transferable to other regions. The importance of social investment analysis in the determination of the social benefits of solar energy investments will be the focus of the paper.

2. SOCIAL RETURN ON INVESTMENT MODEL (SROI)

The Roberts Foundation developed in the 1990s the first SROI model and published their ideas in the report "New social entrepreneurs: The success, challenge and lessons of non-profit enterprise creation (Emerson et al., 1998)." The authors present their methodology for measuring the socio-economic value of social investment (Emerson et al., 1998). The academic success of the new socio-economic framework is demonstrated in a comprehensive literature review by Corvo et al. (Corvo et al., 2022). Peter Weston et al. analysis with the SROI method how farmer manage the dryland in West Africa. Kumara et al. are seeing in SROI framework an innovative model for sub-Saharan Africa to analyse the socio-economic health aspects (Shubha R. Kumara & Aduragbemi Banke-Thomas, 2016). Banke-Thomas also analysis with the SROI method the health sector in sub-Saharan Africa (Aduragbemi O. Banke-Thomas et al., 2014). These papers focus on health and agricultural conditions in Africa, rather than analysing the rural energy sector in West Africa. In the following, the presented SROI approach based on welfare economics focuses on the socio-economic conditions of the rural energy sector in West Africa.

SROI analysis allows you to build an impact model that captures the causality of the solar project (Schober & Then, 2015). The socio-economic impacts of the solar project can be measured and monetised. This allows individual impacts to be aggregated and related to the total input (Schober & Then, 2015). The SROI value reflects the ratio of the monetised impact of the solar installation to the input of the investment into the solar project (Schober & Then, 2015).

The SROI approach (Mette Lindgaard et al., 2014) follows the idea of measuring the overall social impacts of the pilot plant, but also taking into account the specific social returns of the different stakeholder group (Schober & Then, 2015) (Figure 1): Subsistence farmer, smallholders, big farmers, and nomads.

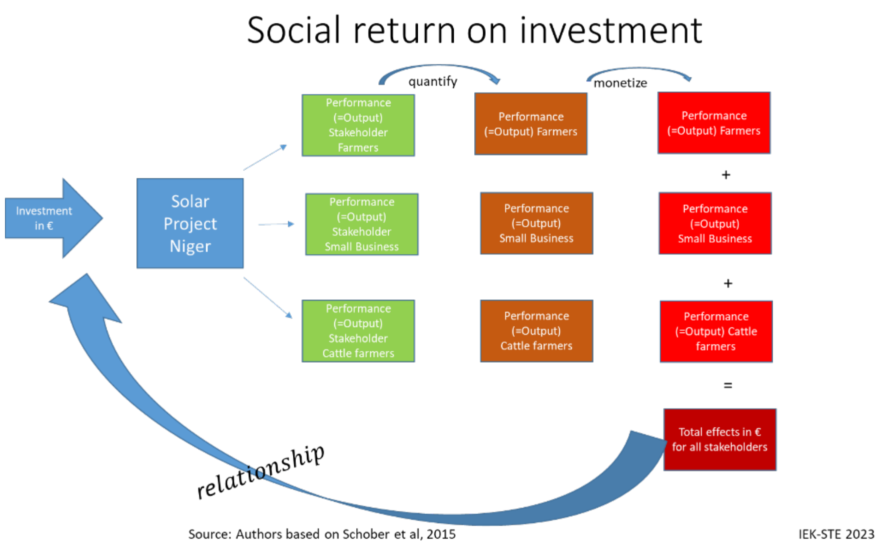

Figure 1 Social return on investment approach

The SROI analysis must determine whether material well-being, health, and educational opportunities are improved for all or only for some stakeholders, or whether personal activities, political, and social relationships are changed by the pilot project. Therefore, the social impacts of the investments must be monetized using stated preference methods (Brown, 2003; Kroes & Sheldon, 1988; Schober & Then, 2015; Seo, 2017b). The result is the SROI value, a measure of the social return on investment (Schober & Then, 2015), as the following formula shows (Nicholls et al., 2009):

$$SROI = \frac{NPV \text{ of monetized utility points}}{NPV \text{ of investments \& operational costs}}, \text{ NPV= net present value} \quad (1)$$

A positive social return is achieved by a SROI greater 1 (Then et al., 2017).

The specific monetised social return on investment of the pilot plant makes it possible to provide data for compensating individual stakeholder groups, if necessary, in order to offset undesirable distributional effects of the pilot plant. The SROI thus allows the social distribution effects of the pilot plant to be determined, which can then be discussed by local, regional and national institutions (Heasley & Delehanty, 1996).

3. THE TIME PREFERENCE AND THE DISCOUNT RATE

A project such as the solar energy project in a village in Niger is implemented when the benefits to the village community exceed the costs incurred. In general, however, the benefits and costs of a project do not occur at the same time, but accumulate over a long period of time. This leads to problems in evaluating investments (Faber et al., 1989).

To compare benefits and costs, the present value of the project is determined by discounting future costs and benefits to a planning date using the discount rate (Musgrave et al., 1975, 1994). The project is implemented if the discounted benefits are greater than the discounted costs. The present value changes significantly with a small change in the discount rate (Faber et al., 1989). The decision whether or not to proceed with a project depends to a large extent on the discount rate used. The more the decision is driven by short-term considerations, the higher the social discount rate (Faber et al., 1989).

Three concepts were identified for the selection of the social discount rate and for the assessment of intertemporal decisions (Faber et al., 1989):

1. The social discount rate is based on the market interest rate (0%-20%) (Courard-Hauri et al., 2020).
2. The social discount rate is politically determined and lower than the market discount rate. This means that the investor, e.g. the government, is more far-sighted than individual investors and individuals (Faber et al., 1989).
3. In the case of climate change, the discounting of future benefits and costs is rejected on ethical grounds. In addition, a 0% or a negative discount rate is advocated (Fleurbaey & Zuber, 2013; Price, 2017).

This means that a justification can be found for any discount rate between 0% and 20% (Faber & Schmutzler, 1989; Faber et al., 1989) to evaluate intertemporal decisions. Intertemporal decisions are decisions whose consequences occur at different times (Hempelmann & Lürwer, 2002). If certain points in time are preferred to other points in time, we speak of time preference (Hempelmann & Lürwer, 2002). A distinction is made between positive and negative time preference (von Nitzsch, 2021). Positive time preference means, for example, that one prefers to consume certain goods today rather than tomorrow. Negative time preference means that one prefers to postpone consumption to the future (Lehmann, 1975). The discount factor $(1+i)^t$ measures, whether the individual has a positive time preference (i>0), a negative (i<0) or an indifferent preference (i=0) (Faber et al., 1989).

In a perfect capital market, the market interest rate can be used to discount future payments. However, recent studies have shown that the market rate does not correspond to consumers' preferences and that individual discount rates exist. Individual discount rates are often much higher than the market rate (Hempelmann & Lürwer, 2002).

As a result of empirical time anomalies - (climate change, size effects, profit-loss asymmetry, excessive discount rates, dynamic inconsistency (discount rate not constant over time)) -, the hyperbolic discounting approach has been developed (Beck, 2014; Rzeszutek et al., 2023).

4. SOCIO-ECONOMIC SITUATION OF RURAL NIGER

In Niger, only 11% of households have access to electricity (2015), with 50% of households in urban areas having access. In rural areas, less than 1% of households have access to electricity. In international dollars, the price of energy for West African households is 30% higher than in Germany.[1]

Electricity price in West Africa (price/kWh)

	Local currency in €	International $ (PPP)
Burkina Faso	0.188	0.6219
Mali	0.200	0.6565
Germany	0.318	0.4503

Source: GlobalPetrolPrices, 2023, Verivox, 2023

Solar power has been discussed as a way to provide low-cost electricity to rural areas without connecting villages to the grid (Charles et al., 2018; Charles et al., 2019; Domegni & Azouma, 2022; Njoh et al., 2019) and to bridge the urban-rural energy divide (Ye & Koch, 2023) also in West Africa.

As an example for rural West Africa, we analyse the socio-economic situation and the household behaviour of a small village in the Dosso region of the state Niger. The village is 80 km outside of Niamey, the capital of Niger. The village has 400 households and about 2200 inhabitants. Households have 5.5 members on average. There are two schools (primary and a secondary school) together with other community centres (health post, kindergarten, mosque). The health centre has a single nurse for aid service. The analysed village is not connected to the electricity grid. To provide the village with energy a 20 KWp PV system will be built. The solar power plant can produce 961,365 kWh electricity over the next 30 years. For the analysis, a price of 39500 € is assumed for the 20 kWp solar plant and a 15 kWh battery. The investment is not financed by the households of the village.

a. Household structure in rural Niger

Against this background, a household survey was conducted to assess the socio-economic conditions of the village before the construction of the solar pilot plant (Table 1). 62% of the households are subsistence farmers, 20% are smallholders and only 15% are see themselves as big farmers. One household lives as a nomad. 37% of the households have less than 0.3 hectares of farmland. 18% have between 0.31 and 0.5-hectare field and 43% of the surveyed households have more than 0.5-hectare farmland, as table 1 shows.

[1] Electricity prices for Niger are not available.

Table 1 Household structure survey

Household Survey - Social structure

	Number households	in %
Subsistence farmer	61	62%
Smallholders	20	20%
Big farmer	15	15%
Nomads	1	1%
Not specified	2	2%
Sum	99	100%
Agricultural structure		
0 hectare (no farm ownership)	1	1%
between 0.01 and 0.10 hectare	21	21%
between 0.11 and 0.20 hectare	5	5%
between 0.21 and 0.30 hectare	11	11%
between 0.31 and 0.50 hectare	18	18%
above 0.50 hectare (value if known)	43	43%
Sum	99	100%

Source: Own calculation, 2023 based on survey, 2021,

b. Household income

Households in the village earn a maximum of 85,600 CFA or €130 per year, according to the household survey, as the following table 2 shows.

Table 2 Annual income

Annual Income (in CFA) of surveyed households

0 - 85,600 (130€)	83	84%
86,000-337,000	/	
337,500-1,510,000	/	
More	/	

Source: Own calculation, 2023 based on household Survey, 2021, / no data

The survey reveals that 87% of the households have no savings, 6% of the households have not more than 1.52€ savings. 6% of the households have savings between 1.5€ and 15€ and only 2% have more than 15€ per year.

c. Rural energy sector

In the following, we will analyse the structure of the energy sector of the village.

Table 3 Energy sector

Energy sector
of the surveyed households

Access to electricity from a Diesel generator or other sources?	households	in %
Yes	15	16%
From time to time	1	1%
Not locally	78	81%
Only in Niamey	2	2%
Sum	96	100%

Source: Own calculation, 2023

Table 3 shows that 16% of the households have constant electricity access from a Diesel generator, whereas 1% have only access from time to time. 81% have not locally access to Diesel electricity and only 2% have access in Niamey.

The people have to buy or collect firewood, as the household survey revealed (table 4).

Table 4 Cooking energy

How do you meet cooking energy demand at home?#)

	households	in %
Firewood (purchased)	4	4%
Firewood (self-collected)	89	88%
Charcoal	2	2%
LPG	6	6%
	101	100%

#) households using more than one cooking energy source

Source: Own calculation, 2023

4% of the households are buying the firewood but 88% collect it by themselves, whereas 2% are using charcoal and 6% uses LPG. 88% uses free energy of self-collected firewood and 12% buying the energy for cooking. The firewood costs in Niger about 0.5€ per day in 2011 and the households need on average 10kg of firewood per day. This firewood has a heating value of 40 KWh and therefore the price per KWh paid by the households is 0.0125€. This is the reference energy price for our model.

5. THE PRICE OF ENERGY – THE VIEW OF THE HOUSEHOLDS

In the Household Energy Expenditure Survey, households were asked to express their expectations regarding the price of energy. 94% of the households hope that energy will not be sold at Niger market prices (0.15-0.2 €/kWh). In addition, 62% of households want basic energy to be free. But only 26% of the households support the idea that the energy consumption above the basic energy needs of the households should be sold by Niger market prices for energy. 55% of the households would like the energy prices in the village to be lower than the normal market prices in Niger. Even 31% of the households would like the energy produced by the new solar system to be free of charge to the households. But 67% of the households reject a free price system.

In conclusion, the majority of the households would like the electricity price of the new PV plant to be lower than the market price in Niger and higher than a free system.

6. SOLAR SROI MODEL RESULTS

A household survey was conducted in the village before the solar plant is scheduled to start operating in 2024.

6.1. Utility points

99 households of the 400 households were asked to assess the effects pilot plant in general with points between 1 and 10 for themselves (for you) and for the village community. The household survey revealed that the households highly value the importance of the pilot plant for themselves and their family as well as for the village community. Figure 2 shows that the households rated the importance of the plant for their own family (for you) higher than for the village community (community).

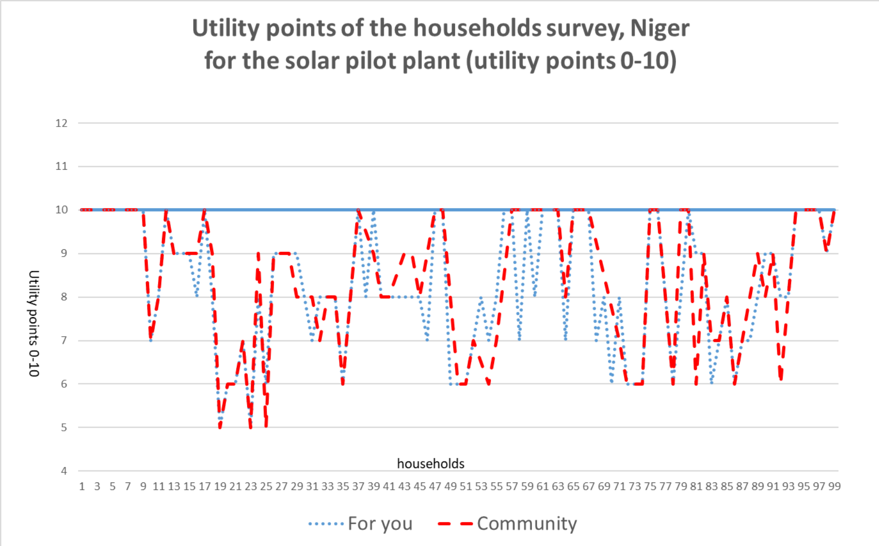

Figure 2 Utility points of household survey 2021

Figure 2 shows how the utility points are distributed across the individual households. In total, households awarded 809 points for the importance of the plant for their own households and 714 points for the benefits the plant has for the village community. The worst score for the village community and for their own family was 5 and the best score was 10. No household scored the plant worse than 5 points.

6.2. Utility points and the time preference

We have seen that the time preference rate can change over time. Figure 3 shows that the utility points decrease over time due to the time preference of different households. The effects of five different time preference rates are analysed (-0.1, 0, 1, 5, 10), which represent the different assessment of the pressure put on the households by climate change and the effects of the war in Ukraine that started on 2/24/22 and causes an increase in energy and food prices.

Utility points are distributed over time using the HD equation (HD), which is built on the idea of hyperbolic and standard discounting (Ahlbrecht & Weber, 1995; Beck, 2014; Huber & Runkel, 2005). It is assumed that the pressure of current socio-economic conditions causes households to behave in a time-inconsistent manner. (Huber & Runkel, 2005; von Nitzsch, 2021). Therefore, the HD equation is used to distribute the surveyed utility points over the next 30 years:

$$HD = \frac{1}{\left(1+(tp \cdot t)\right)^{t}}, \text{ tp=time preference rate, t=time, HD=hyperbolistic distribution} \quad (2)$$

Based on the HD equation, the distribution of the utility points over time can be determined depending on the time preference rate, as the following equations show:

We assume 4 different time preference rates:

$$\text{-0.001\%, } Y = 0.0402x^3 - 0.2087x^2 + 6.5074x + 794.41 = 33586 \quad (3)$$

$$\text{1\%, } Y = -0.0074x^4 + 0.4873x^3 - 9.0088x^2 + 4.2382x + 860.15 = 7774 \quad (4)$$

$$\text{5\%, } Y = 0.0034x^4 - 0.3593x^3 + 13.252x^2 - 203.65x + 1115.1 = 3812 \quad (5)$$

$$\text{10\%, } Y = 0.0106x^4 - 0.8368x^3 + 23.481x^2 - 275.96x + 1155.9 = 2871 \quad (6)$$

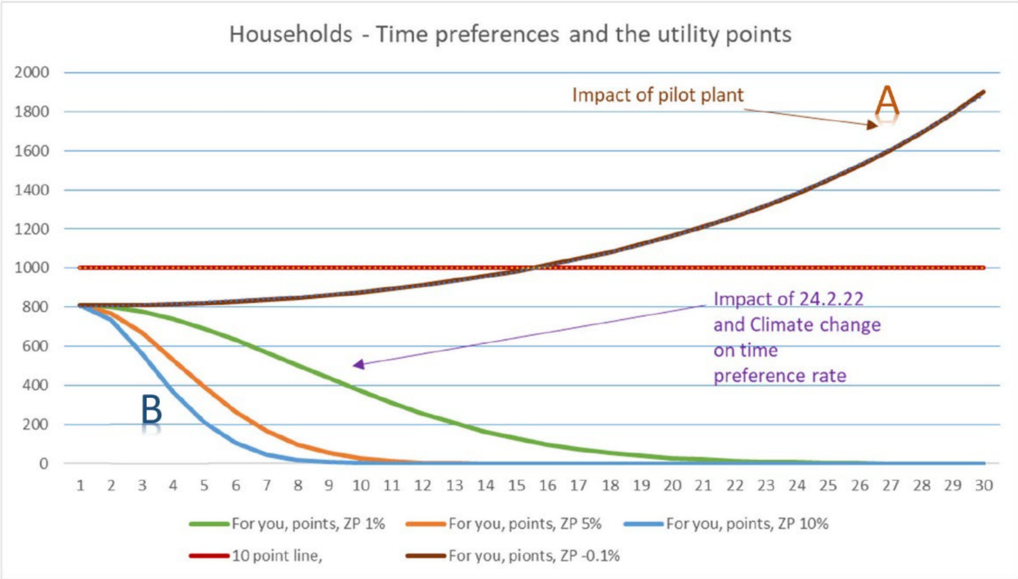

Figure 3 Household survey – utility points

If we assume a time preference rate of 1%, we get for all surveyed households (7774) utility points over the 30 years. By increasing the time preference rate to 5% and 10% the utility points are reduced over the 30 years to 3811 and 2871 points. The maximum utility points over the 30 years are 33586 representing a time preference rate of -0.001%.

Based on this analysis, we obtain a Utility Opportunity Space (UOS) determined by different time preference rates representing different socio-environmental-economic circumstances. The new equation expresses the area between the A-brown-(-0.001%)-line and the B-blue-10%-line.

$$A = f\left(x_{-0.001}\right) = \int_{1}^{30} 0.402x^3 - 0.2087x^2 + 6.5074x + 794.41 = 33586$$

$$B = f\left(x_{0.1}\right) = \int_{1}^{30} 0.0106x^4 - 0.8368x^3 + 23.481x^2 - 275.96x - 1155.9 = 2871 \quad (7)$$

$$UOS = A - B = 33586 - 2871 = 29354$$

The positive time preference rates can be interpreted as the valuation of the solar plant before its completion, and the negative time preference rate can be interpreted as the valuation of the solar plant after its commissioning. The solar plant can mitigate the negative effects of inflation and climate change for the village.

6.3. Monetizing on the basis of stated preferences – WTP

The next step of the SROI analysis is quantifying the social impact of public and private policies and investments by monetizing. Monetization is a method of aggregating the various impacts of an investment and relating them to the investment. Positive aggregated impacts increase the SROI and negative impacts decrease it. Monetary valuation has the appeal of easy intuitive comprehension, comparability with market prices and the possibility of aggregation (Then et al., 2018).

The stated preference method used to monetise the utility points is the willingness-to-pay approach. Stated preferences are a direct way of getting information about people's willingness to pay (Blomquist, 2015; OECD, 2006; Seo, 2017a). The households of the village are directly asked how they value the pilot plant.

Based on the household survey, the willingness of households to pay for energy is revealed to be 0.15 €/kWh. This price is used to monetize the utility points (UP) of all households of the village: monetary impact = MIj.

$$MI_j = \sum_{i=1}^{400} UP_i \cdot WTP_j\left(kWh\right), \text{ i=households, j=village, UP= utility points, MI= monetary impact} \quad (8)$$

6.4. Social return on investment

In the next step, the key data of the model are defined. We assume that a 15 kWh battery costs €15,000 in Niger and the 20 kWp solar system costs €24,500. The energy operating costs are €3,976 per year, of which €731 are for technology issues and €3,245 for the wages of workers. This results in an energy operating cost of $119,286 over 30 years. These values are a conservative estimate as they do not take into account inflation and wage increases.

Table 5 Key data

Key data SROI Model	
Investments	
Energy investments	**in €**
Battery 15 kWh	15000
Solar 20 kWp	24500
Total	39500
Annual Operating Costs	
Energy	
Technical Costs per year	731
Wages Solar Kiosk per year	3245
Energy-Operating Costs over 30 years	119286
Solar Energy Production	
Solar energy production 30 years, 1% degradation in kWh	961365

Source: Own data 2023

The Levelised Cost of Electricity (LCOE) is the cost of converting energy from another form of energy into electricity (Kuckshinrichs & Koj, 2018). The expenses (EXP) are the sum of the investments (I), the maintenance (M), the operating (O) and the fuel costs (F) during the operating period. These costs are discounted to the present value (t=0) with a certain interest rate (r) (Bertoni, 2021).

$$EXP = \sum_{t=0}^{n} \frac{I_t + M_t + O_t + F_t}{\left(1+r\right)^t} \quad (9)$$

LCOE is based on the Net Present Value (NPV) concept (Bertoni, 2021; Kuckshinrichs, 2021). All issues are discounted to an initial point in time that corresponds to zero.

The energy yields (E) result from the energy produced, discounted to the present. This is expressed in the following formula:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + M_t + O_t + F_t}{\left(1+r\right)^t}}{\sum_{t=0}^{n} \frac{E_T}{\left(1+r\right)^t}} \quad (10)$$

Solar electricity price based on operating and labour costs, energy investments and 5% inflation per year over the next 30 years is 0.71€/kWh for the village in Niger.

$$StP_{01} = \frac{\text{NPV Operating+Labor Costs+Energy investments+5\% inflation}}{\text{NPV Solar Energy Production}} = \frac{508201\text{€}}{705949kWh} = 0.71\frac{\text{€}}{kWh} \quad (11)$$

This solar electricity price for the village is higher than the willingness to pay of the households, the average Niger electricity market prices and the firewood reference price.

Based on these data the SROI is determined for three different hyperbolic distributions – 1%, 5%, 10% - of the utility points over time. For each distribution the monetized value of the utility points are discounted by four standard discount rates (0, 0.01, 0.05, 0.1).

Table 6 SROI of all costs

SROI=MVUP/Investment-L-B-K, 30 years, 5% Inflation - utility points monetised by WTP				
LSROI=(NPV-MVUP/NPV all costs)				
LSROI MVUP	NPV MVUP 0.0	NPV MVUP 0.01	NPV MVUP 0.05	NPV MVUP 0.1
LSROI (1%)	0.0092	0.0068	0.0020	0.0005
LSROI (5%)	0.0150	0.0111	0.0033	0.0007
LSROI (10%)	0.0506	0.0375	0.0113	0.0025
Source: Own calculations 2023 based on survey 2021, considering all households of the village				

Table 6 shows that the SROI decreases further by considering all relevant costs and investments for the solar power plant. All SROI values are below 1, the investments are not causing a positive social return for the village. The households cannot bear the investment, operating and labour costs. The social rate of return decreases as the time preference rate, which represents the social, economic, and environmental pressures on village households, increases.

7. SOLAR POWER PLANT A MERIT GOOD?

Based on the previous results, the question arises as to whether it is appropriate to use all the investments and costs caused by the pilot plant as the basis for calculating the SROI, or to follow the idea of the solar plant as a merit good (Andel, 1984; Becchetti et al., 2020). Merit goods are goods and services that the government believes people will under-consume, and which can be subsidised or provided free at the point of use (Musgrave et al., 1975, 1994). Both the government and the private sector can provide merit goods. Unlike pure public goods, merit goods can be rivalrous, excludable and refusable (Ver Eecke, 2003). It is often argued that the consumption of merit goods generates positive externalities - where the social benefits of consumption exceed the private benefits (Musgrave et al., 1975, 1994). Merit goods are goods for which the private demand is lower than the social desirability of the good (Dilnot & Helm, 1987; Hoberg & Strunz, 2018; Mann, 2003).

In our case, there is not a single private investor who would build a solar power plant in this small town in Niger, so solar power can be interpreted as a merit good. One result of the SROI model is that the solar power plant cannot be built and operated using market-based economic instruments alone.

Therefore, the question arises: What portion of the investment, operating, and labour costs of the solar pilot project can be refinanced by the village households and generate a positive social return on investment for the households?

Table 7 Break Even SROI

NPV causing a SROI >1					
NPV, Investment, O+L-Costs, 30 years, 5% inflation, for all households, WTP based kWh price					
Monetary VUP - hyperbolic	Investment	ZP 0%	ZP 1%	ZP 5%	ZP 10%
1%	508201	4640	3430	1031	229.5
Source: Own calculation, 2023					IEK-STE 2023

Table 7 shows the costs that the village household has to bear in order to generate a positive social return. The cost that households would be able to bear falls from €4640 to €229.5 as the rate of time preference rises. These costs represent the break-even positive SROI.

8. CONCLUSION

The analysis has shown that the SROI method is suitable to analyse the socio-economic effects of new investments in the energy infrastructure of a village in rural Niger and has reveal the importance of the time preference rate of the households of the village for the interpretation of the results. For the analysis, a comprehensive picture of the socio-economic-ecological situation of the village is necessary and can be revealed by a household survey. The household's valuation of the solar investments is measured in terms of utility points. The points can be monetised using the willingness to pay method. This data can be used to calibrate the SROI model.

The model results reveal that the investment does not generate a positive social return for the planned investment against the background of the set model assumption. I.e. the households of the village cannot refinance the solar power plant. Therefore, the break-even SROI is determined. It determines the amount of investment costs that the village and its households can bear to generate a positive SROI, depending on the time preference rate of the households.

For energy investments in Niger, the SROI model shows, that time preference and discount rate affect the results. Local data collection through household surveys in rural areas is mandatory because data on energy consumption and energy prices are not available for rural Niger. The research approach presented here provides a new picture of the socio-economic conditions in rural Niger and can serve as one model for the analysis of energy investments in rural Africa.

The next research questions are

- how the merit good (Musgrave et al., 1975, 1994) "solar power plant" can be managed as a common property good (Ostrom, 1990) by the households of the village, and
- how the solar investment can be reorganised and managed in the sense of E. Ostrom's "polycentric governance of complex systems (Ostrom, 2009)" to generate a positive SROI as reported by Olivia Rauscher for Ethiopia (Rauscher, 2023).

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