More than 300 Solar Thermal Systems as a Result of a Training and R&D Co-operation

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Abstract

Countries in Southern Africa suffer massive electricity shortages and regular power cuts for years. A significant part of electricity is currently being converted into low-temperature heat. To solve this problem and to exploit the huge solar thermal potential, seven research institutes and universities from Austria, Botswana, Lesotho, Mozambique, Namibia, South Africa, and Zimbabwe as well as local solar companies co-operate since 2009 in the SOLTRAIN project.

Up to now, 3,000 people have been trained in 110 training courses, and the lessons learned in the courses have been implemented by local companies in 326 demonstration projects. The installed solar thermal systems span the range from small plants with 2 m² collector area for hot water preparation for single-family homes to systems that supply industrial processes with up to 600 m² collector area. In 2018, the two largest solar thermal systems in Sub-Sahara Africa were built in the course of this project. The annual solar yield of all the plants installed since 2009 adds up to 3,533 MWh and CO_2 savings of 1,222 tons.

In order to support broad roll out programmes of solar thermal systems in all six participating countries Solar Thermal Roadmaps and Implementation Plans were developed in broad stakeholder processes in close cooperation with policy. Last but not least - an extensive program to support students in their master's thesis completes the project.

Keywords: Solar Thermal, Training, Demonstration Systems, Monitoring, Roadmaps and Implementation Plans

1. Introduction

The SADC region[1] faces a huge power deficit due to a lack of investment in the power sector. Over 80% of the electricity is generated from coal. A subsequent eminent disruption to the power supplies in the SADC Region is a major threat to the economic growth currently being experienced.

The key problems in the African electricity sector:

- Low level of electrification and inadequate power plant output - Only 24% of the people who live south of the Sahara have access to electricity. If one excludes South Africa, the total installed power plant capacity south of the Sahara is only 28 GW.
- Low reliability - On average African companies face 56 days of power outages per year. That results, according to the World Bank, in losses of 6% of sales revenue. In areas where diesel back-up generators are not available, losses due to power outages increase to around 20%.
- High cost - Electricity tariffs in Sub-Saharan Africa average US $ 0.13 per kilowatt-hour. Due to low reliability of power supply many companies, hotels as well as the public sector, operate diesel generators. The electricity costs resulting from this way of handling electricity shortages are two to three times higher.

Measurements carried out in the SOLTRAIN project in Namibia and South Africa show that in the household sector 40-50% of the electricity is used for domestic hot water preparation as soon as there is a connection to the electric grid available. Thus, solar water heaters would be one of the major options in order to reduce electricity

[1] The Southern African Development Community (SADC) is an inter-governmental organization with 16 Southern African countries as members.

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demand and subsequently environmental effects like CO_2 emissions caused by fossil power plants. SADC member states have excellent solar irradiation with more than 2000 kWh/m² annual radiation and estimates from the International Energy Agency (IEA) suggest that solar thermal systems could meet about 70 – 80% of the regions low-temperature heating and cooling demand.

Due to these reasons, SOLTRAIN is designed to support and contribute to the implementation of the different energy policies of the target countries that enhance the use of solar thermal systems.

Moreover, energy poverty negatively affects the situation of large numbers of people worldwide and particularly in the SADC Member States. There are close links between energy supply and practically all aspects of sustainable development such as access to water, agricultural and industrial productivity, health care, education, job creation, environmental pollution and climate change.

Another focus of SOLTRAIN is to contribute in reducing energy poverty by improving access to sustainable energies, specifically solar thermal solutions, and thus directly contributing to the realization of the United Nations Sustainable Development Goals SDG 7 and indirectly to SDG 1, SDG12 and SDG 13.

2. Current Status of Solar Thermal Utilization in Sub-Sahara Africa

African countries have excellent annual solar irradiation, which lies between 1800 kWh/m² and 2400 kWh/m². The availability of solar radiation is one of the highest worldwide and available in all African countries. Despite this fact, the use of solar thermal energy in African countries is still on a very low level in comparison with other regions of the world. In 2018 the share of the capacity installed in Sub Saharan Africa was 0.3% of the total capacity worldwide. 82% of the worldwide capacity of 480 GW_{th} was installed in China and Europe, with comparatively low solar radiation (Weiss and Spörk-Dür, 2019).

The main reasons for not using solar thermal systems extensively according to the outcome of a review conducted in all six project partner countries were:

- Lack of promotion
- The high up-front capital cost of solar thermal systems compared to electric water heaters of similar capacity.
- The absence of low-interest finance to assist with the high upfront cost of solar thermal systems
- Poor installation, freezing problems, and low maintenance
- Lack of a coordinated coherent energy policy

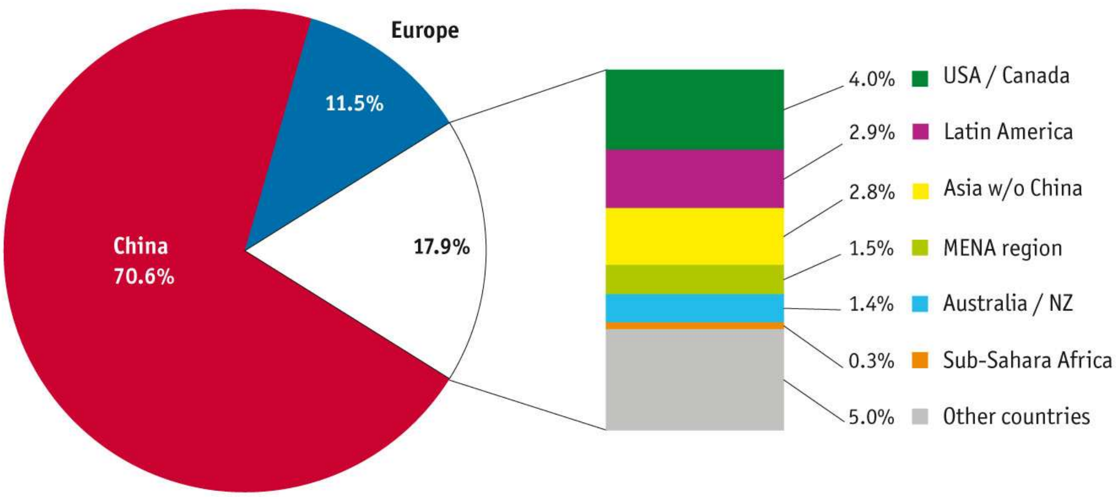

Fig. 1: Share of total installed capacity in operation by economic region at the end of 2016 (Weiss and Spörk-Dür, 2019)

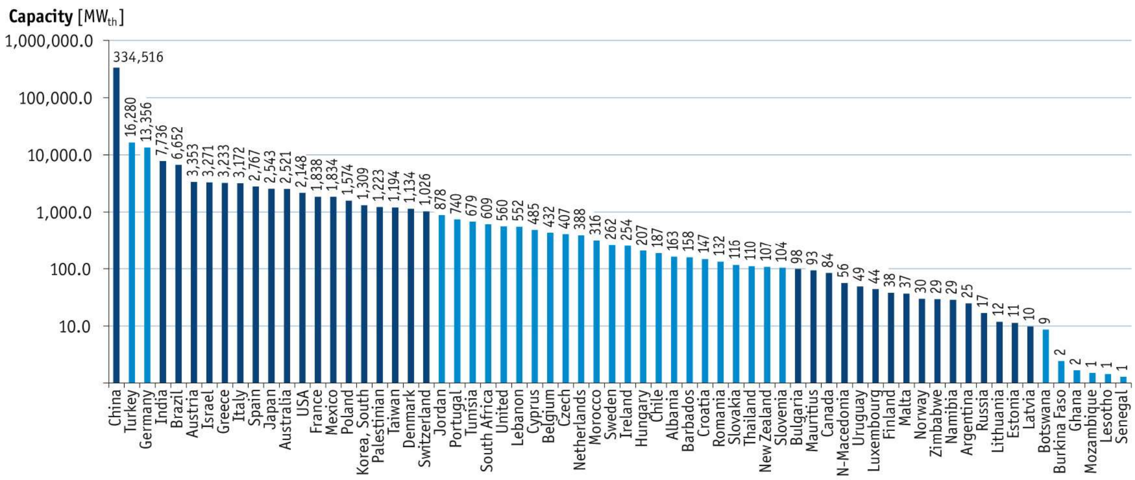

Fig. 2: Total capacity of glazed water collectors in operation in kWth per 1,000 inhabitants in 2016 (Weiss and Spörk-Dür, 2019)

2.1 Local market potential

By increasing the standard of living and access to electricity in the project countries also the hot water consumption will rise in the residential sector, in hotels, hospitals and industry in future.

Assuming that the SOLTRAIN partner countries had the same hot water consumption per capita as the countries with the worldwide highest solar thermal market penetration (Cyprus and Israel), an annual electricity demand of about 73.842 GWh would be needed in the six project partner countries annually to prepare domestic hot water. This result was gained based on the assumption that the SOLTRAIN partner countries had the same solar thermal market penetration as the two leading countries had reached already in 2012 (466 kW_{th}/1000 inhabitants).

The electricity consumption avoided in such a way would equal the amount of basic electricity for the entire population, or 2000 kWh/a for 36.9 Million households of the SOLTRAIN partner countries. In other words: Investing in solar thermal systems could significantly reduce investment and running cost for power plants as well as for fuel imports in the partner countries.

Table 1: Potential annual electricity savings and avoided CO_2 emissions due to the installation of solar thermal systems

Country	Population	Installed capacity	Annual Electricity savings	Basic electricity for	Annual CO2 avoidance
		kWth	GWh	number of households	Million Tons
Botswana	2 155 784	1 005 673	1 628	814 116	1
Lesotho	1 942 008	905 947	1 467	733 385	1
Namibia	2 198 406	1 025 556	1 660	830 212	1
Mozambique	24 692 144	11 518 885	18 650	9 324 812	13
South Africa	53 006 857	24 727 699	40 035	20 017 661	27
Zimbabwe	13 771 721	6 424 508	10 402	5 200 792	7
SOLTRAIN Countries	97 766 920	45 608 268	73 842	36 920 979	50

3. Overall Project Structure

In order to be successful with the broad deployment of solar thermal systems in Southern Africa it is necessary to have a coherent strategy to promote this technology. The overall approach and the elements of the project for a broad, successful and sustainable implementation of solar thermal systems are illustrated in Figure 3 below. Ambitious targets were set in well-defined Solar Thermal Roadmaps and Implementation Plans. Based on these targets a comprehensive training program on all educational levels was defined. The trained persons apply their knowledge in demonstration systems to prove that they understood the contents of the training.

For broad implementation, financial incentives are necessary in most countries provided by banks or by the government. Regulations are essential when it comes to quality control and warranties. Last but not least, awareness campaigns are necessary in order to inform the public and relevant stakeholders about the benefits of the technology and national research and development capacities (R&D) have to be built up if support of local production shall be established.

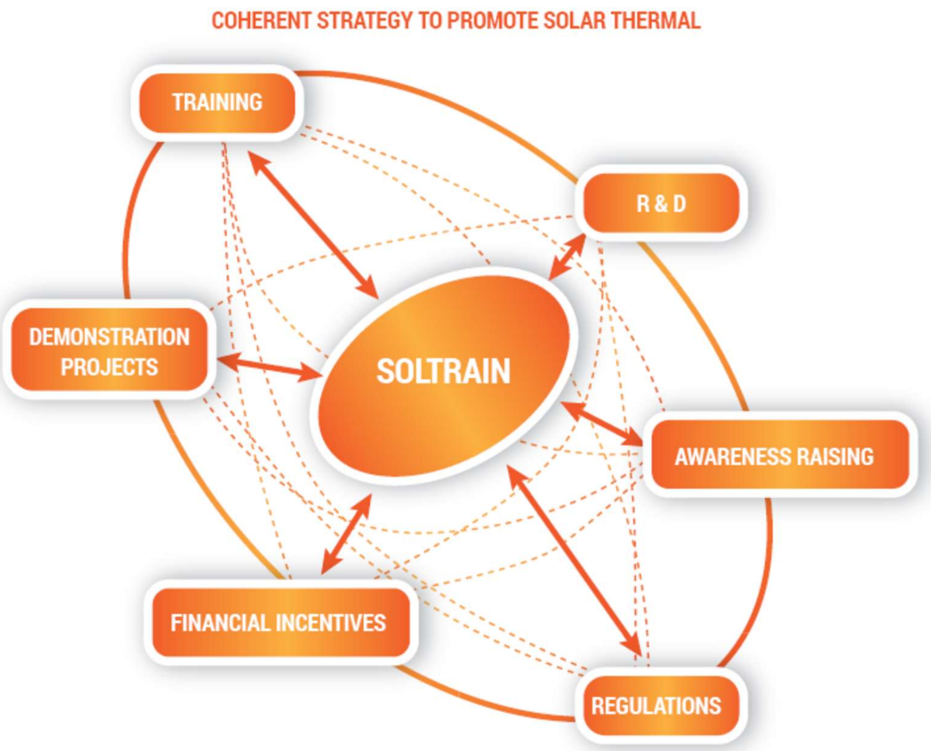

Fig. 3: Elements of the SOLTRAIN project

4. Training and Demonstration Systems

Up to now, about 3,000 people have been trained in the six partner countries in 110 training courses, at universities, vocational training centers and solar thermal companies.

The lessons learned in the courses were applied and implemented by the project partners in co-operation with local companies. So far 326 demonstration projects were installed in the partner countries. The installed solar thermal systems span the range from small plants with 2 m² collector area for hot water preparation for single-family homes, plants with 20 - 50 m² collector area at social institutions, hospitals and student dormitories or hotels to large-scale systems that supply industrial processes with up to 600 m² collector area.

In 2018, the two largest solar thermal systems in Sub-Sahara Africa were built as part of the project. One of these two large-scale systems is the 1st district heating plant in South Africa. The second system supplies heat to the processes of a tannery.

The total installed collector area of the 326 systems equals 4621 m², corresponding to an installed capacity of 3.24 MW_{th}.

Fig. 4: The size of the demonstration plants installed in the course of the project ranges from 2m² to 600m² collector area

An essential focus of the training was on different plant concepts. The participants of the training courses should be able to adapt systems to the respective user's demands and the existing framework conditions. The plant portfolio ranges from simple thermosyphon systems to complex large-scale pumped systems with the integration of waste heat.

Table 2: Overview of the different system types by country installed in phase III of the project

Type of System	South Africa	Zimbabwe	Namibia	Mozambique	Botswana	Lesotho	Total
Pumped systems	31	0	3	0	3	4	41
Pumped systems with heat pump	3	0	0	0	0	0	3
Indirect thermosyphon systems	1	8	49	4	0	10	72
Direct thermosyphon systems	0	21	0	0	0	0	21
Direct PV supplied hot water system	1	0	0	0	0	0	1
PV pumped systems	0	1	0	0	0	0	1
Total	**36**	**30**	**52**	**4**	**3**	**14**	**139**

5. Monitoring

In order to prove the performance and reliability of the solar thermal systems for users as well as for political decision makers, 21 of the solar thermal systems were equipped with monitoring devices in order to measure solar yields and to evaluate the performance of the systems in detail. All these systems are equipped with heat meters, a data logger, radiation sensors and temperature sensors.

The systems were monitored for 12 months. They show specific annual solar yields between 516 kWh/m² and 823 kWh/m². This proves the excellent performance of these systems.

The following figure shows monthly energy balances of a detached house built as part of an affordable housing program of the Namibian Housing Enterprise in Windhoek. The annual solar yield of the plant was 690 kWh/m². The solar fraction is well over 90%. Only in the winter months June and July electrical backup was necessary.

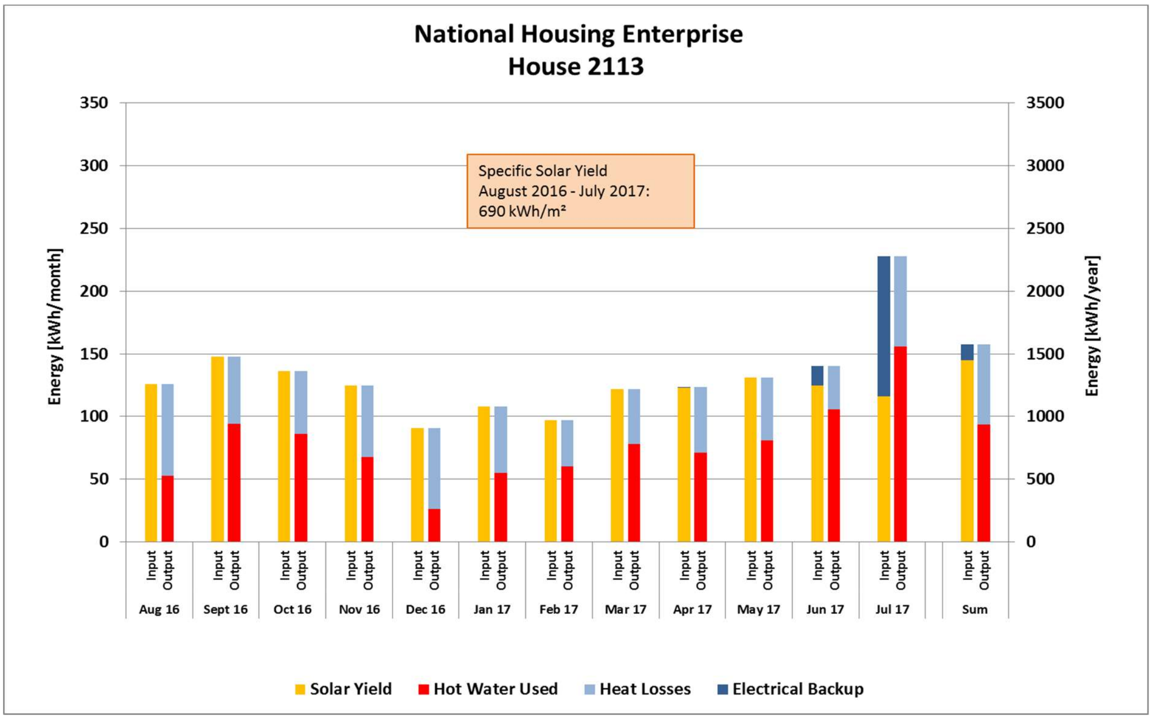

Fig. 5: One-year energy balance for a monitored system at National Housing Enterprise, House 2113, Windhoek, Namibia

Other measurements in the course of the project have shown that as soon as households have access to electricity, up to 50% of the electricity demand is used to heat hot water. With correct design of the solar water heating systems, the hot water demand can be covered up to 100% by solar energy, whereby the additional costs for the solar thermal system was in the range of 1 to 3% in relation to the overall construction cost of a single-family house.

All solar thermal systems built as part of the project provide a solar yield of 3,531MWh/year, with electricity savings of around 3,887 MWh/year and savings of 1,222 tCO_2/year (CO_2 savings based on oil equivalent).

Table 3: Energy savings and avoided CO_2 of all 326 demonstration systems

Country	Total collector area [m²]	Total capacity [kW$_{th}$]	Number of systems	Solar yield [MWh/a]	Electricity savings [MWh/a]	Avoided electricity cost [ZAR]	CO_2 reduction [t_{CO2}/a]
Mozambique	57	40	6	50	55	118 160	17
Namibia	512	359	123	465	512	1 095 297	160
South Africa	3 286	2 300	121	2 346	2 581	5 520 641	814
Zimbabwe	468	328	49	395	435	931 368	135
Lesotho	176	123	24	160	176	377 255	56
Botswana	122	85	3	115	127	271 946	40
TOTAL	**4 621**	**3 235**	**326**	**3 531**	**3 887**	**8 314 667**	**1 222**

If one kWh of electricity is valued at 0.2139 South African Rand (ZAR), the installed demonstration systems save ZAR 9.9 million (= approx. EUR 640,000) of electricity cost per year.

Comprehensive comparative measurements between conventional thermosiphon systems and direct photovoltaic supplied water heating were also carried by AEE INTEC in cooperation with Stellenbosch University in South Africa. The installed power of the direct PV-supplied solar hot water system is 1.5 kW_p. The conventional thermosyphon solar water heater has a collector area of 2.4 m². Both systems are equipped with an identical 200 litre hot water tank.

Fig. 6: Direct PV-supplied hot water system (left) and conventional thermosyphon system (right) in an experimental set up

The figures below show the energy balances of the two systems from April 2018 to April 2019. It should be noted that the hot water consumption of the PV-supplied system was significantly lower than that of the thermosiphon system. This also explains the high heat losses of the hot water store in the PV-supplied system.

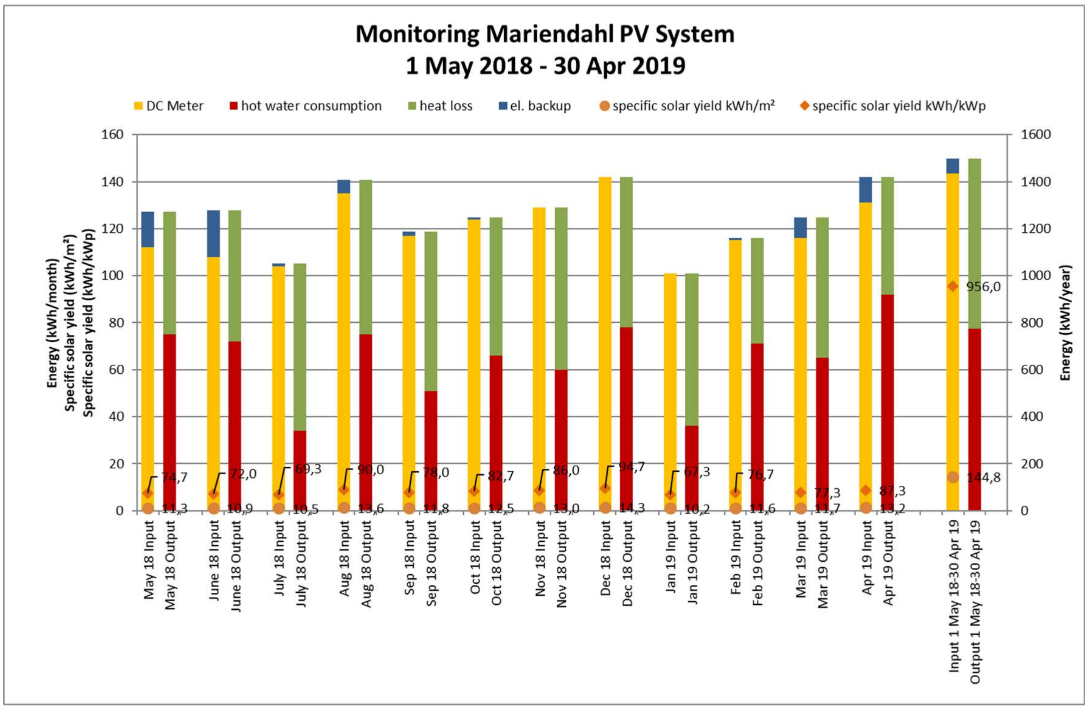

Fig. 7: Energy balance of the PV-supplied solar hot water system from May 2018 to April 2019

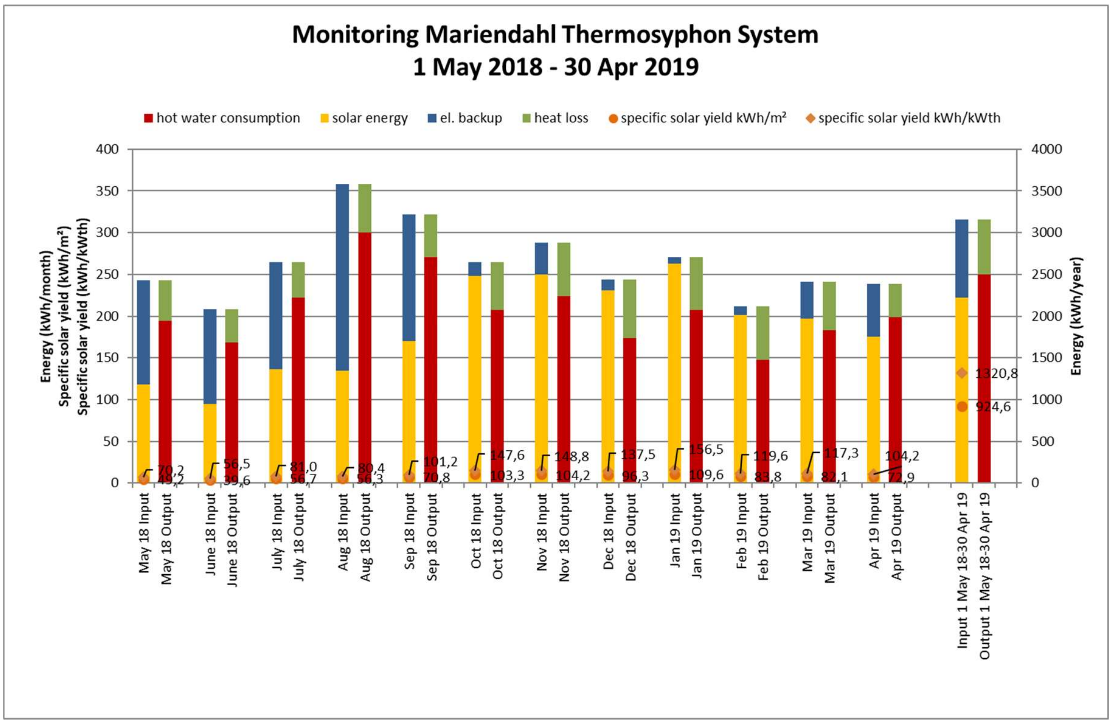

Fig. 8: Energy balance of the thermosyphon solar hot water system from May 2018 to April 2019

6. Implementation of Solar Thermal Roadmaps

In the course of the project, "Solar Thermal Roadmaps and Implementation Plans" have been developed in broad stakeholder processes for all six partner countries. These roadmaps have taken into account national programs on sustainability and energy efficiency. Therefore, the Roadmaps and Implementation Plans could contribute to the specific work programs for the widespread roll out of solar thermal systems in the participating countries in the coming years. In phase 4 of the project, which started in July 2019 political decision-makers will be supported in implementing the set goals for their countries.

One promising project that could contribute to the rapid implementation of the Namibian Solar Thermal Roadmap is the Osona Village project. In an area of 1100 ha in Osona in the Okahandja community, about 60 km north of Windhoek, 10,000 apartments, a vocational training campus and a business park are to be built in the coming years. Among other requirements, each of the residential buildings has to be equipped with a solar thermal system.

The motivation for the obligatory installation of solar thermal systems is the significantly reduced cost of the electricity infrastructure. The installation of the solar hot water systems is expected to reduce the electricity demand of the households by 40 - 50%. To achieve this in reality requires the installation of durable and reliable systems. Currently, the SOLTRAIN project is working on a comprehensive quality assurance concept.

7. Acknowledgments

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8. References

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