**Technical, Economic, and Social Feasibility Study for the Implementation of a Sustainable Energy Solution for Domiz 1 Refugee Settlement**

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## List of Abbreviations

| | |
|---|---|
| a | Year |
| A | Ampere |
| AC | Alternating Current |
| ACTED | Agency for Technical Cooperation and Development |
| AUK | American University of Kurdistan |
| BCF | Barzani Charity Foundation |
| CE | Conformité Européenne |
| DC | Direct Current |
| DMCR | Department of Migration and Crisis Response |
| EEG | Erneuerbare-Energien Gesetz (Renewable-Energies-Act) |
| EN | European Standard |
| h | Hour |
| HTA | High Tension between 1 kV and 50 kV AC |
| HTB | High Tension exceeding 50 kV AC |
| I | Electric Current |
| IDP | Internally Displaced Persons |
| IEC | International Electrotechnical Commission |
| IRENA | International Renewable Energy Agency |
| ISO | International Organization for Standardization |
| IQD | Iraqi Dinar |
| KRI | Kurdistan Region of Iraq |
| kV | Kilovolt |
| kVA / MVA | Kilovolt-ampere / Megavolt-ampere |
| kW | Kilowatt |
| kWh | Kilowatt hour |
| kWp | Kilowatt peak |
| LCOE | Levelized Cost of Energy |
| LPG | Liquefied petroleum gas |
| MWp | Megawatt peak |
| MWh | Megawatt hour |
| O&M | Operations and Maintenance |
| PPA | Power Purchase Agreement |
| PR | Performance Ratio |
| PV | Photovoltaic |
| TA | Technical Advisor |
| TC | Technical Consultant |
| U | Voltage |
| USD | United States Dollar |
| UNHCR | United Nations High Commissioner for Refugees |
| V | Volt |

# 1 Executive Summary

This report provides an overview of the technical, economic and social situation within Domiz 1 refugee settlement in the Duhok region of the KRI to ascertain the feasibility of implementing a sustainable energy solution centered around a PV power plant. The report is based upon a field study carried out by atmosfair, AUK and UNHCR with the support of Selco Foundation from January to March 2022. The study included the installation of electrical meters to measure real time energy consumption, door-to-door surveys of households and businesses as well as interviews with field staff and government officials. The findings build upon those of a previous study by UNHCR and IRENA conducted in September 2019 as well as the installation by atmosfair of a similar PV system at the Mam Rashan IDP camp in the Duhok region. This study aims to capture the effects of the Covid-19 pandemic on the situation in the camp as well as propose concrete recommendations for the construction of a PV power plant.

All of the households in Domiz 1 currently receive free electricity from the public grid provided by the Ministry of Electricity. However, similar to the rest of the country, the camp suffers frequent blackouts. Households have access to back-up electricity through a parallel grid connected to privately-owned community diesel generators. Residents pay for the electricity they use from the diesel generators based upon the size of their connection with households paying approximately IQD 52,500 (USD 36) per month, amounting to an average of 11% of household expenses. The diesel generators often suffer power fluctuations and households are unable to use all of their appliances on the back-up supply. The generators are also highly polluting, producing thousands of poisonous chemicals which have a damaging effect on the environment and health of the local population.

The site is eminently suitable for the installation of a PV power plant with minimal earthworks required, easy access and sufficient labor available for construction and maintenance. There is support for the project from the residents and at all levels of government. Eight potential interventions, centered around the installation of a PV power plant at the settlement, were assessed as part of the study. Each scenario relied upon a financing model that combined a grant and equity to be repaid over 10 years. Equity repayments and maintenance and operation costs were calculated to be covered by household and business electricity payments with fees ranging between USD 15 and USD 25 and the sale of carbon credits. This would ensure that all options would lead to improved electricity supply, a reduction in carbon emissions and a decrease in household expenditure on electricity. In addition, a core component of each scenario is the establishment of a community fund financed through the project cash flow and extra user fees to support capacity building and energy efficiency interventions in the camp.

Of the scenarios assessed, the report recommends options A1 and A2 that utilize the national grid without a back-up system. These would require that the public grid is constantly available to ensure 24-hour electricity supply to the residents. These two options are the most economically attractive for investors, allow the lowest fee for residents, and would result in the greatest reduction in emissions. Version A2b would also be financially viable without an initial grant showing the potential for PV adoption within the KRI more widely. In conversations with the Ministry of Electricity they indicated constant supply from the public grid was both technically possible and desirable, though this will require further clarifications. If this proves not to be viable alternative options B1-B2 also offer a significant reduction in greenhouse gas emissions and improve households' access to energy at a reduced cost.

The project team recommends continued engagement with local, national and international stakeholders to build upon the current support for the project. These discussions will be vital

to determine which solution to pursue and consequently the grand/equity ratio which will need to be secured.

| | | Public Grid Parallel | | | | | | Seperate Grid Infrastructure | |
|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical schedule | |
| Source | Unit | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| PRO & CON (Technical) | | + high coverage of daily demand + give back more energy to the grid than supplied + continues 6A for the consumers - technical oversized system -system not available if the grid is not available | + Lowes LCOE + significant coverage of demand + continues 6A for the consumers -grid need to provide more than before - system not available if grid is not available | + lowes CO2-foodprint + low/good LCOE - requires still diesel Gen on site - PV overproduction is lost | + low CO2-foodprint + low/good LCOE - requires still diesel Gen on site - smart meteiring or switch technical required - PV overproduction is lost | + no change in schedule + 6 A for the consumers - high Diesel consumption - High CO2 footprint - high LCOE | + no change in schedule -high Diesel consumption - High CO2 footprint - high LCOE | + no grid interconnection required + 6A for the consumers - high Diesel consumption - high CO2 footprint -high LCOE - extra grid infrastructure required | + no grid interconnection required - high Diesel consumption - high CO2 footprint -high LCOE - extra grid infrastructure required |
| PRO & CON (Economical) | | economical very interesting: + low basic fee of 15USD/month; + equity ratio 32%; - required grant 11 Mio. USD | economical very interesting: + basic fee of 15USD/month, + equity ratio 68%, + grant 2,5 Mio. USD | economical feasible, but: - basic fee 25USD / month, - equity ratio 21%, - required grant 13,5 Mio. USD | economical feasible, but: + basic fee 20 USD / month, + equity ratio30%, - required grant 8 Mio. USD | not economical | economical feasible, but: - basic fee 22USD / month, - equity ratio 10%, - required grant 10 Mio. USD | not economical | economical feasible, but: - basic fee 25USD / month, - equity ratio 11%, - required grant 10,5 Mio. USD |

**Table 1: technical and economical comparison of scenarios A1-D2**

## 2 Summary

The technical, economic and social feasibility study was conducted from January-March 2022 coordinated by the American University Kurdistan and atmosfair gmbh alongside colleagues from the UNHCR and with support from Selco Foundation. The survey involved discussions with local officials and on-site staff as well as in-person interviews with camp residents, the data was collected through the KoBo toolbox. Across the camp interviews were conducted with 44 daily operation facilities (100% of total), 47 shops (8% of total) and 324 households (6% of total). Households and shops were selected using systematic sampling to ensure the sample was representative of the twelve districts in the camp.

To assess a realistic load profile, three electrical meters were installed on “Feeder-Level” - a cable that supplies up to 50 households with a capacity of 6A (1.3 kW) per household - allowing the measurement of real time energy consumption. In this way, 83 households were monitored from January 20$^{th}$ to March 13$^{th}$ in the Farasheen district of the camp. To provide a full picture of the annual load curve, additional data was used from an existing PV-storage system in the nearby IDP camp Mam Rashan.

### 2.1 Social Economic Project Description

The main results of the social economic survey come from the in-person interviews where respondents provided information about their household income and expenses with a specific focus on their current energy infrastructure and satisfaction with the energy supply. Incomes across the camp varied depending upon the occupation of the main earner. A large number of households rely upon income from workers in the construction industry where income varies

depending upon the availability of work. For the initial construction of the project as well as maintenance and operation there would be sufficient labor available within the camp.

Currently households receive electricity from the public grid through a 6A connection for free. They also have access to electricity through a 3A connection to a back-up community diesel generator which they pay for monthly. The price of electricity from the diesel generator varies depending on the availability of the public grid and price of diesel. Households currently spend approximately IQD 50,811 (USD 36) per month for energy from the diesel generator which amounts to 11% of their household expenses. As households pay for energy based on their connection rather than usage this is a higher percentage for lower income households. The availability of the public grid also affects households' use of electrical appliances. Basic devices like lights, fans and TVs can function efficiently on the current back-up diesel generator while more energy intensive appliances like washing machines, electric heaters and refrigerators only run on the public grid.

Based upon the information provided, all the scenarios developed had a monthly fee per household of between USD 15 - USD 25 with 2.5% of the lowest income households receiving electricity for free. The income from these fees would cover the operation and maintenance costs of the system as well as any equity repayments within 10 years. This would ensure the long term sustainability of the project while also resulting in residents paying less for a more reliable supply of cleaner electricity. Additional revenue from the project would finance a community fund which would support capacity building and energy efficiency efforts within the camp.

Respondents indicated their desire for a more reliable, affordable energy supply and spoke specifically in favor of solar energy should it meet these requirements. This support for solar energy was echoed by the Governor of Duhok and representatives from the Ministry of Electricity who voiced their support for the project. Both at the regional and governorate level there is a push for the development of solar energy with a number of projects planned and already under construction.

## 2.2 Technical Economic Project Description

The current energy demand of the camp is 24598 MWh/year covered by the public grid and the diesel generator back-up. It is expected that the energy demand will slightly increase in the future with an improved electricity supply. However, as the current energy use is highly inefficient, the potential to decrease the energy demand in the future was also considered.

Eight different scenarios were simulated all with the aim to provide a sustainable, uninterrupted power supply for the camp. In six scenarios (A1 - C2) the system would be connected to the existing public grid and in two scenarios (D1-D2) a separate grid infrastructure would be required. Within Domiz 1 there are two sites available that can be used for the installation of the PV system with accompanying storage. Even the biggest proposed PV system of 16.6 MW under scenario A1 would fit on those sites.

| | | Seperate Grid Infrastructure | Public Grid Parallel | | | | | | Seperate Grid Infrastructure | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Typical Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical schedule | |
| Source | Unit | Public Grid & Diesel (Current Status) | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| PV-System Capacity | Power/MW | - | 16.6 | 6.9 | 11.5 | 6.9 | 11.5 | 7 | 11.5 | 6.9 |
| Battery-System Capacity | Power/MW | - | - | - | 6.0 | 4.0 | 6.0 | 5 | 6.0 | 4.0 |
| | Energy/MWh | - | - | - | 8.4 | 5.6 | 8.4 | 5 | 8.4 | 5.6 |
| Supply by PV/ESS | Energy/MWh | - | 14,035 | 10,816 | 14,184 | 9,996 | 6,270 | 5,291 | 6,676 | 4,676 |
| Diesel Power | Power/MW | | | | 4.0 | 3.0 | 5 | 3 | 5 | 3 |
| Supply by Diesel | Energy/MWh | 10,502 | - | - | 3,633 | 2,570 | 9,483 | 5,211 | 9,077 | 5,826 |
| Diesel consumption | Liter | 3,276,586 | - | - | 1,133,496 | 801,840 | 2,958,639 | 1,625,794 | 2,832,074 | 1,817,781 |
| Supply by Grid | Energy/MWh | 14,096 | 15,699 | 18,918 | 12,032 | 12,032 | 14,096 | 14,096 | 14,096 | 14,096 |
| Possible Feed-IN | Energy/MWh | - | 17,251 | 2,130 | - | - | 8,209 | 6,935 | - | - |
| Load | Energy/MWh | 24,598 | 29,849 | 29,849 | 29,849 | 24,598 | 29,849 | 24,598 | 29,849 | 24,598 |
| PRO & CON (Technical) | | | + high coverage of daily demand<br>+ give back more energy to the grid than supplied<br>+ continues 6A for the consumers<br>- technical oversized system -system not available if the grid is not available | + Lowest LCOE<br>+ significant coverage of demand<br>+ continues 6A for the consumers<br>- public grid need to provide more electricity than before<br>- system not available if grid is not available | + lowest CO2-footprint<br>+ continues 6A for the consumers<br>+ low/good LCOE<br>- requires still diesel Gen on site<br>- PV overproduction is lost | + low CO2-footprint<br>+ low/good LCOE<br>- requires still diesel Gen on site<br>- smart meteiring or switch technical required<br>- PV overproduction is lost | + no change in schedule<br>+ 6 A for the consumers<br>-high Diesel consumption<br>-High CO2 footprint<br>- high LCOE | + no change in schedule<br>-high Diesel consumption<br>-High CO2 footprint<br>- high LCOE | + no public grid interconnection required<br>+ 6A for the consumers<br>- high Diesel consumption<br>- high CO2 footprint<br>- high LCOE<br>- grid infrastructure required | + no public grid interconnection required<br>- high Diesel consumption<br>- high CO2 footprint<br>- high LCOE<br>- extra grid infrastructure required |
| PRO & CON (Economical) | | | economical very interesting:<br>+ low basic fee of 15USD/month<br>+ equity ratio 32%<br>- required grant 11 Mio. USD | economical very interesting:<br>+ low basic fee of 15USD/month<br>+ highest equity ratio 68%<br>+ grant 2,5 Mio. USD | economical feasible, but:<br>- basic fee 25USD / month<br>- equity ratio 21%<br>- required grant 13,5 Mio. USD | economical feasible:<br>+ basic fee 20 USD / month<br>+ equity ratio30%<br>- required grant 8 Mio. USD | not economical | economical feasible, but:<br>- basic fee 22USD / month<br>- equity ratio 10%<br>- required grant 10 Mio. USD | not economical | economical feasible, but:<br>- basic fee 25USD / month<br>- equity ratio 11%<br>- required grant 10,5 Mio. USD |

**Table 2: comparison of scenarios A1-D2 in energy and technical/ economical aspects**

The most cost effective and climate friendly scenario would be the connection of the PV power plant to the national grid without a back-up system (scenario A1 and A2). This would require the public grid to be constantly available to ensure residents had uninterrupted access to electricity. During initial conversations with the utility provider they demonstrated this would be both technically and administratively possible. However, final clarification is required as to whether 100% grid availability is politically acceptable, physically possible and can be guaranteed. Specifically, it will be important to ascertain the likelihood of power failures which under this scenario would leave the camp without a back-up system.

Scenario A1 would be of particular interest to the utility provider, as the PV system would produce an overcapacity of electricity above that required by Domiz 1. This surplus electricity can then feed-in to the public grid, which would result in more electricity going into the grid than the utility currently supplies to the camp. This means the PV system would not only enable a 24/7 electricity supply within the camp, but would also increase the available electricity across the public grid. This additional electricity could be used to supply other refugee camps in the area like the nearby Domiz 2.

Scenario A2 is also highly interesting from an economical point of view, particularly in the iteration A2b which can be financed purely through equity/loans without the necessity of a grant. This demonstrates the commercial viability of PV systems in the KRI even in the most vulnerable populations. However, A2+A2b both rely upon the utility provider supplying more electricity to the camp than they currently are. These scenarios are therefore only possible with strong political support. A further option could be raising the basic fee paid by households or charging for the additional amount of electricity provided. There is room within the current pricing for both options though these would have to be explored further.

| | A1 | A2 | A2b |
|---|---|---|---|
| Size of PV Plant | 16.6 MW | 6.9 MW | 6.9 MW |
| Total investment costs | 16,135,000 USD | 7,890,000 USD | 7,890,000 USD |
| Required amount of | 11,000,000 USD | 2,500,000 USD | 0 USD |

| | | | |
|---|---|---|---|
| grant | | | |
| Basic fee to be paid by the households | 15 USD/month | 15 USD/month | 20 USD/month |
| Revenues carbon credits | 170,038 USD | 170,038 USD | 170,038 USD |
| Cash flow available for the community fund during payback time equity | 87,659 USD | 186,896 USD | 69,339 USD |
| Cash flow available for the community fund after payback time equity | 764,705 USD | 903,749 USD | 1,127,198 USD |

**Table 3: cost and cash flow for scenarios A1, A2, A2b**

If scenarios A1 and A2 are not possible then the installed PV system would require a backup battery storage system combined with a diesel generator (scenarios B and C). This backup system would allow the public grid within the camp to continue running and “black-start” in the case of wider power failures on the grid. In this case the most cost effective and climate friendly scenario would be an electricity supply through the PV system during the day and a supply through the public grid during the night. This would require the utility provider to change their current supply schedule for the camp to a night schedule, however doing so would reduce the amount of electricity they would need to supply to the camp overall. Based on the availability of funding from international donors and the willingness to pay for the improved electricity supply from residents, it can be determined whether the households are supplied with a 6A (scenario B1) or a 4A (scenario B2) connection.

| | B1 | B2 |
|---|---|---|
| Size of PV Plant | 11.5 MW | 6.9 MW |
| Size of Battery System | 6 MW | 4 MW |
| Size of Diesel Generator | 5 MW | 3 MW |
| Total investment costs | 17,140,941 USD | 11,496,706 USD |
| Required amount of grant | 13,500,000 USD | 8,000,000 USD |
| Basic fee to be paid by the households | 25 USD/month | 20 USD/month |
| Revenues carbon credits | 97,378 USD | 118,638 USD |
| Cash flow available for the community fund during payback time equity | 89,785 USD | 160,307 USD |
| Cash flow available for the community fund after payback time equity | 676,493 USD | 693,896 USD |

**Table 4: cost and cash flow for scenarios B1 and B2**

If the utility provider is unwilling to change the supply schedule the installed system requires a high share of diesel generated electricity. This is independent of whether the system is connected to the public grid (scenarios C1 + C2) or is using a seperate grid infrastructure (scenarios D1 + D2). The diesel savings compared to the status quo are much lower in scenarios C and D than in scenarios A and B. This also creates a high system LCOE owing to high fuel costs as well as a high CO2 footprint. Scenarios C1 and D1, in which the households are connected with a 6A connection, are economically not feasible under the limited payment capacity of the households.

| | C2 | D2 |
|---|---|---|
| Size of PV Plant | 6.8 MW | 6.9 MW |
| Size of Battery System | 5 MW | 4 MW |
| Size of Diesel Generator | 3 MW | 3 MW |
| Total investment costs | 11,069,706 USD | 11,846,706 USD |
| Required amount of grant | 10,000,000 USD | 10,500,000 USD |
| Basic fee to be paid by the households | 22 USD/month | 25 USD/month |
| Revenues carbon credits | 65,820 USD | 53,513 USD |
| Cash flow available for the community fund during payback time equity | 60,956 USD | 81,479 USD |
| Cash flow available for the community fund after payback time equity | 258,171 USD | 323,707 USD |

**Table 5: cost and cash flow for scenarios C2 and D2**

## 2.3 Risk Factors for the Project

The following table summarizes the probable risks to the project assigning a value to each and highlighting the measures required to address them. Each point is subsequently examined in detail in the relevant chapters of the report. There are no issues which forestall the development of the project, with different options available depending on the outcome of consultations with relevant stakeholders.

| | |
|---|---|
| Critical: effect shape of the project | |
| Not critical: possible to solve | |
| No risk | |

| Sr.-No | Subject | Risk description | Risk Value | Risk Mitigation |
|---|---|---|---|---|
| 1 | Geographic parameters | Land ownership clear | No risk | |
| 2 | Climatic conditions | Heat | Not critical | Batteries with cooling system, choice of modules |
| 3 | Environmental Aspects | Flooding, earthquakes, sandstorms | Not critical | Taken into account with mounting structure and choice of modules. |
| 4 | Topography and grounding | Uneven ground | Not critical | Earthworks included within cost estimation |
| 5 | Irradiation Data | No shading | No risk | |
| 6 | Transport Access | Transport access is good | No risk | |
| 7 | Water Access | Water access is restricted through boreholes with limited supply required for camp | Not critical | Installation of rainwater storage system for cleaning of modules |
| 8a | Grid Access | Feeder also connected to Domiz 2 requiring possible separation | Not critical | Reworks might be required - included in costs |
| 8b | | Option A1 and A2 only possible if grid 100% available | Critical | Consultations with government and utility provider otherwise selection of different option |
| 10 | Inability to Pay | Change in households' economic situation affecting their ability to pay the basic fee for electricity. | Not critical | Preference for projects which would entail lowest fee from households. Models based on 2.5% of households receiving free electricity. |

| Sr.-No | Subject | Risk description | Risk Value | Risk Mitigation |
|---|---|---|---|---|
| 11 | Political Opposition | Change in local leadership resulting in opposition to the project. | Not critical | Close cooperation with local and national government |
| 12 | Long-term Sustainability | Camp closure | Not critical | Assurances of transition to settlement |
| 13 | Legal and energy policy | Changes to not allow grid access | Not critical | Legal contract on grid access |
| 14a | Resistance from Population | Resistance from camp residents | Not critical | Clear explanation of project, improved electricity supply at reduced cost |
| 14b | | Resistance from host population | Not critical | Close cooperation with local government |
| 15 | Protection of Most Vulnerable | Increased burden on income | Not critical | Continue current practice of means-tested support to low income households. |
| 16 | Commercial Resistance | Loss of business | Not critical | Try to include diesel operator into the business case and political support to proceed the project. |

**Table 6: assumed occurrence probabilities and estimated effects of risks**

## 2.4 Recommendations for Action / Outstanding Items

The report outlines a number of sustainable energy solutions which could be implemented within Domiz 1 centered around the construction of a core PV power plant. The next phase of the project will be to hold further discussions with the Office of the Governor of Duhok and the Ministry of Electricity to decide which model to take further. As outlined above this is especially pertinent regarding systems A1 and A2 which rely upon constant energy from the public grid to ensure 24/7 electricity to the settlement without the need for a backup diesel generator or battery system. Once the system has been agreed the project team will prepare a consolidated project proposal to present to donors as well as local and international business partners to secure financing for the construction and operation of the system as well as the governance structure of the community fund.

# 3 Social (Pre-)Feasibility Study

## 3.1 Baseline Scenario

The Domiz 1 refugee settlement was established in April 2012 to host Syrian refugees in the Duhok province of the KRI. With approximately 30,800 inhabitants residing in 5,333 shelters, it is one of the largest refugee settlements in the MENA region. Unlike many temporary refugee settlements in conflict situations, Domiz 1 has developed into an established neighborhood of Domiz Town. Inhabitants reside in brick or concrete houses with running water, sewage connection and separate kitchens. Owing to ethnic and cultural similarities, the inhabitants of Domiz 1 have largely been welcomed by the host population, with many camp residents working in the nearby city of Duhok and many residents of Domiz Town utilizing services within the settlement.

The UNHCR has been overseeing the management and operation of Domiz 1 since its conception in coordination with the local government. Refugees within KRI falling under the responsibility of the DMCR with the camp management for Domiz 1 currently subcontracted to the BCF. There are also a range of national and international non-governmental organizations providing services and support within the camp including ACTED, World Vision, Save the Children and the Norwegian Refugee Council.

All of the houses in the settlement are connected to the national grid with a 6A connection, with electricity currently provided free of cost by the Ministry of Electricity. However, similar to the rest of the country, the camp suffers frequent blackouts. This poses severe challenges to living conditions, particularly in the winter and summer when electrical devices are used to deal with temperatures between -2 and 9°C from December to February and reaching 40 to 45 °C from June-September.

In addition to the public grid there are fourteen community diesel generators servicing the settlement each with a capacity of 850 KVA. The generators are run by a private company with the permission of the local government. Households are connected to these generators through a 3A connection to a parallel grid. Households pay for the connection based upon an aggregate of the electricity supplied from the diesel generators across the whole settlement. The price for electricity from the community diesel generators varies per month depending upon the availability of the public grid and the price of diesel.

Figure 1 below illustrates the categories and availability of appliances within the households while Figure 2 provides an overview of the typical usage of appliances within households. The lower ampere connection means households can only operate level 1 appliances when electricity is provided by the community diesel generators with level 2 appliances such as washing machines, water boilers, and electric cooking stoves unable to be used.

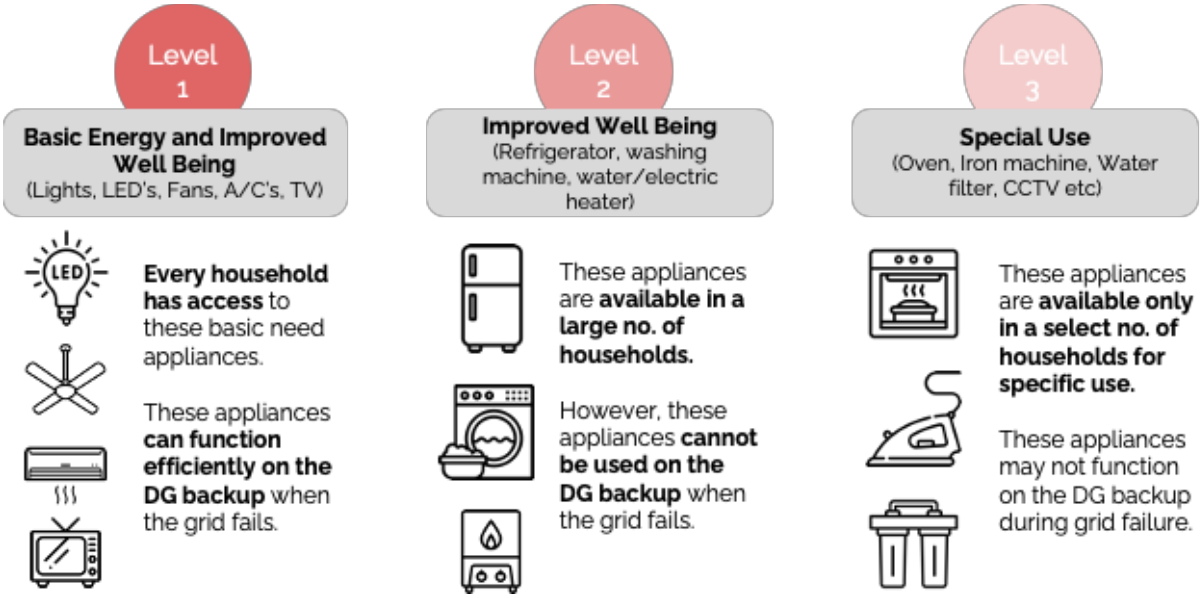


**Figure 1: Appliance Categorisation**

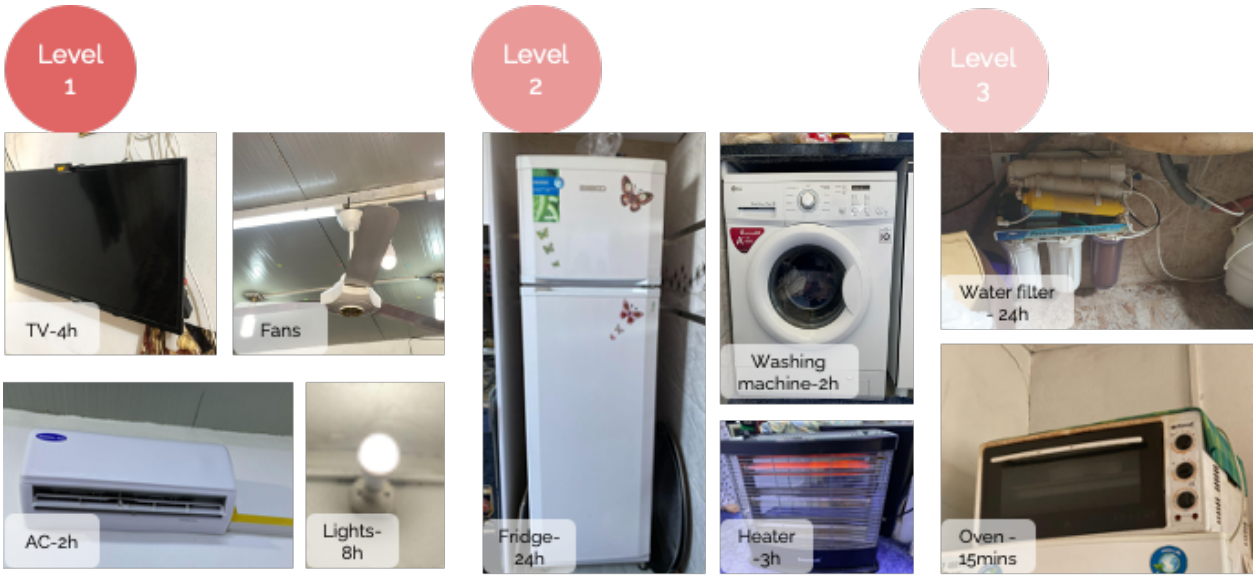


**Figure 2: appliance usage in the settlement**

All residents currently rely upon LPG as their main source of cooking fuel. LPG canisters are easy to obtain with a service that delivers them directly to households upon request. Households reported that the price of LPG fluctuates although currently a normal sized canister costs IQD 9000 (USD 6.17) which is the average used by 75% of households per month. Only 4% of households spent under this amount with 17% using two or more canisters per month costing IQD 18000 (USD 12.34) or over.

Of the houses surveyed 64% didn't report any challenges because of a lack of cooking fuel with 16% reported suffering cooking delays and 4% skipping meals. Others mentioned that they relied upon the support of family and friends or using alternative fuels for cooking should they struggle to obtain LPG.

Around 20% of households reported already owning an electrical cooking device such as an electric stove or hot plate. Due to the amount of energy these devices required households generally only used them on the public grid. Of those who don't already own an electrical device 66% said that they would consider using one for cooking although they raised concerns regarding the reliability of electricity and cost of these devices. These were the same concerns voiced by those who were skeptical of switching to electricity. Only around 2% indicated they would be unwilling to switch to electricity for cooking as they believed it was more dangerous than LPG.

There are currently no plans from the Ministry of Electricity to increase supply of electricity to Domiz 1 settlement. The KRI is generally facing a significant shortfall in energy. The current electricity supply of 3000 MW meets roughly half the region's demand, which runs at approximately 5000 MW in summer and reaches 7000 MW in winter. Energy demand is expected to continue to rise, further placing a strain on current infrastructure. The Kurdistan Regional Government has committed to significantly increase solar energy in the region with three 25 MW solar power plants planned in the Duhok, Erbil and Sulaymaniyah governorates. The KRG akims to have installed at least 900 MW of solar capacity by 2030.

## 3.2 Social situation within the camp

### 3.2.1 Camp structure

The population of Domiz 1 has remained consistent at around 30,800 since January 2016. The residents are exclusively asylum seekers from Syria, with a combined 69% originating from the northeastern Syrian cities of Quamishl and Al Malika. The population is evenly split between male and female with 48% of the population aged under 18. Of these 1043 are designated as children at risk. Other vulnerable groups include individuals with disabilities, older persons at risk and those suffering serious medical conditions. Accurate records of the residents are regularly maintained by UNHCR in collaboration with local partners. Household vulnerability is assessed by camp management to provide targeted assistance including fuel and food allowances. Many residents work in the construction sector as day-laborers with sufficient labor available for the installation and operation & maintenance of the plant from the local population.

There are eight schools in the settlement with capacity for 7655 students. Due to the limited number of school places, children are only able to attend in either the morning or afternoon. There are two main health facilities in the camp - German Health Center and Haly kar Organization with an additional Maternity Clinic located in the Sarbasti district. These provide basic care although residents also visit specialists in the surrounding area. Approximately 2.5% of residents suffer from a serious medical condition with a further 2.5% classified as having a disability.

### 3.2.2 Living conditions

The housing conditions are similar for all shelters in the settlement. Each shelter has its own plot of between 104-114 $m^2$. The shelters are built upon a concrete slab base - some shelters having tiled floors - with concrete walls that are either plastered or not plastered. The shelters are single storeyed at 2.5 meters high. The roofs are made of sandwich panels on top of a

steel bar frame. Households aren't currently allowed to have concrete roofs as this would enable residents to claim land ownership under Iraqi law. Each shelter has water and sewage connections with a separate room or building for the kitchen, latrine and shower.

**Figure 3: housing conditions**

Of the households surveyed 33% reported recurring expenses for wall finishing and waterproofing due to wall dampness and water leakage during winter and heavy rainfall accompanied by mold on the walls. Apart from the expenses, these conditions can result in poor indoor air quality leading to conditions like Sick Building Syndrome

**Figure 4: interior building conditions (source: clean middle east)**

### 3.2.3 Employment and Businesses

Many of the residents work in the local area of Duhok with a range of backgrounds represented. The main areas of experience residents have are as laborers in construction, manufacturing and building sectors (28%) and homemakers (also 28%). There are a wide range of other professional backgrounds among residents including personal service workers (3.6%), drivers (2.3%), craft workers (1.8%), teachers (1.5%) and electricians (0.2%).

There are both established shops on the main streets within the camp as well as shops and businesses that are run directly from households. An overview of the shops within Domiz 1 can be found in Figure 5 below.

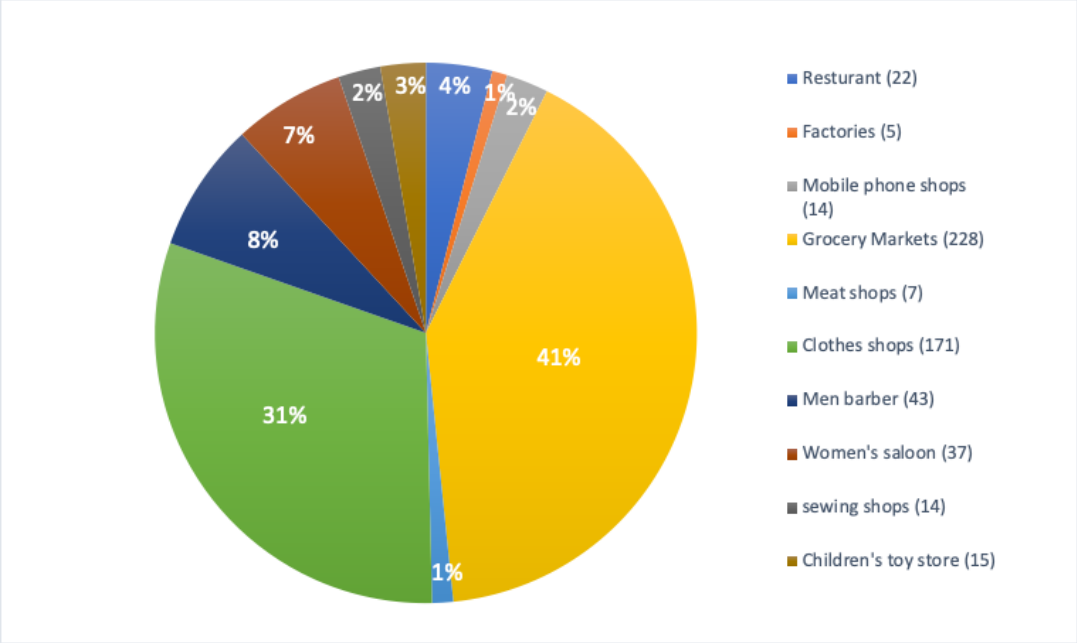


**Figure 5: Categorizing of shops in Domiz 1**

**Figure 6: Examples of shops in Domiz 1**

### 3.2.4 PV Business and Training

Currently renewable energy companies operating in the KRI are relatively small with their operations focused on the supply and installation of small PV and battery systems for local households and small businesses. However, there are also companies that design and install larger industrial projects as well as off grid systems. There is also a growing awareness both at the societal and political level within the KRI of the potential for PV to provide a low-cost and sustainable supply of electricity. A number of international organizations have developed small-scale solar projects with local partners, while a United Nations Development Program (UNDP) project sponsored by the European Union plans to install a minimum 2 MW of energy in the University of Duhok.

Initiatives to increase awareness of PV within the region and federal Iraq have also taken place. GIZ has organized a 'Training of Trainers' series aimed to equip experienced electricians with the tools needed to conduct training on the installation and maintenance of PV technologies. These trainers can provide a valuable source of local knowledge/labor that can be used to train residents of Domiz 1 as part of the installation of the selected PV-system as well as offer options for further training through the community fund (see section 5.2.8).

# 4 Technical (Pre-) Feasibility Study

## 4.1 Energy demand

An accurate picture of the overall energy demand and time of demand are crucial for the proper design of any electrical supply and distribution system. For this study we used as much truly measured data as possible to build up the possible supply proposal on a realistic basis.

### 4.1.1 On household level

To assess a realistic load profile, we measured the energy at the “feeder-level”: a cable that supplies up to 50 households with a capacity of 6A (1.3 kW) per household.

The two selected feeders were in the Farasheen district of the camp and had 44 and 39 households connected. They were monitored over almost two months from the 20th January to the 13th March.

The results showed a low variance both daily and weekly across the monitored timeframe. A comparison of the monitored households with those across the different sectors in the camp demonstrated that the sample was representative of the whole camp.

The consumption profile differs from winter to summer, as electrical heaters are used as part of the winter heating creating a much higher load. This is a trend seen across the KRI. The summer load profile is dominated by electrical air coolers with a lower load.

### Winter Profile

The weather during the measured period was rather cold making it representative of winter in the camp. Measured data was reviewed and analyzed to create an hourly profile for a day.

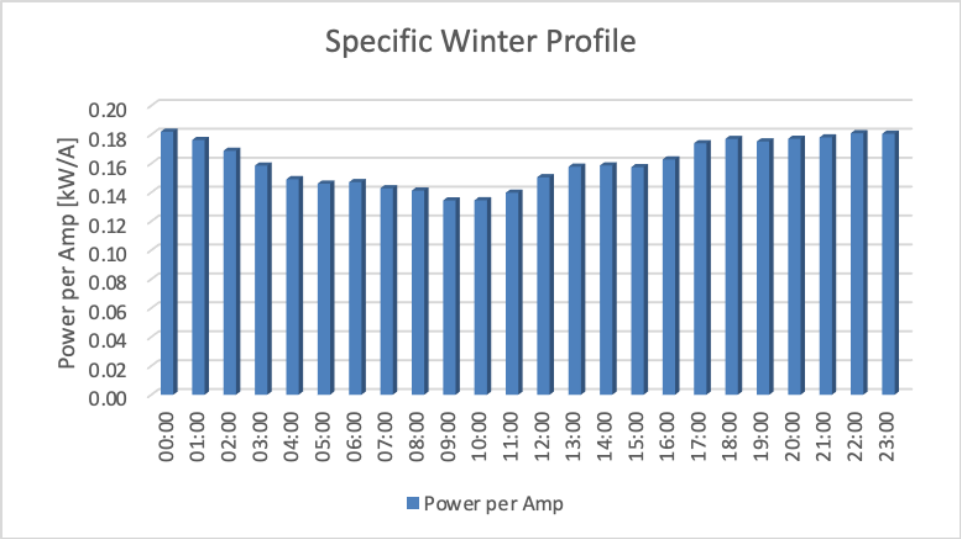


**Figure 7: Specific Power per Ampere Profile for Wintertime**

The profile in Figure 7 shows the peak load is at night when temperatures are at their lowest, and people are consequently using heating devices the most.

The grid availability in the measured timeframe was 50.6% meaning the public grid was on for about 12h per day. The grid schedule changes daily so the profile was calculated by using data from when the public grid was available at each time. During the monitored period, supply was provided at least 5 times per time slot. For the profile the average of each time slot was used and normalized to 1 ampere.

## Summer Profile

The summer profile was created from 3 years of measurements in a different camp in the KRI and shows different characteristics based on the changed needs. The approach is the same as for the winter profile and based on more than 2000 households. As the measurements were linked to the times when the public grid is unavailable and supplied through a solar powered battery system the night values are extrapolated from early morning and late at night data when the battery system was supplying the households.

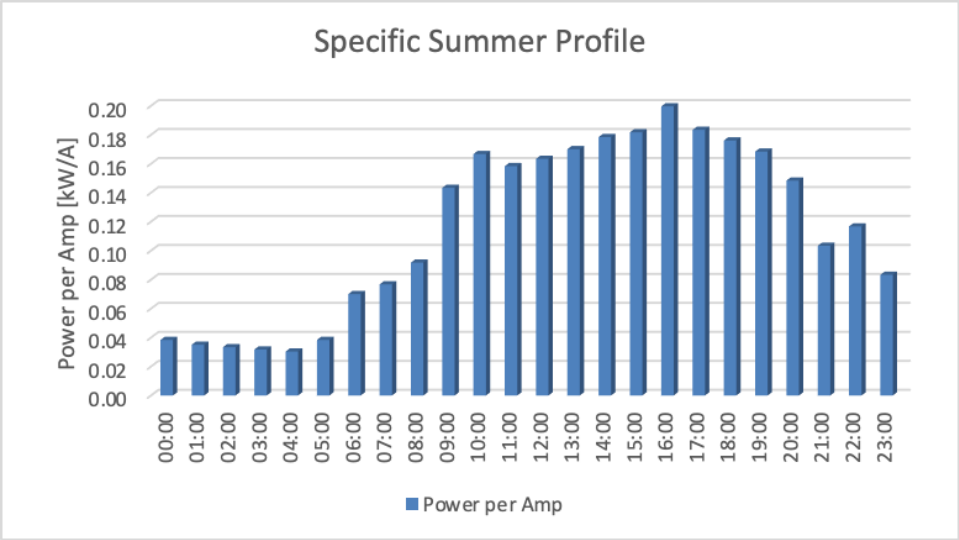


**Figure 8: Specific Power per Ampere Profile for Summertime**

The highest demand is in the afternoon when everyone is trying to get out of the heat and air coolers are operating.

### 4.1.2 On production level

The load profile for shops, other small and medium businesses was assessed with the same methodology described in chapter 4.1.1. The feeders which were measured, mostly had shops connected to them along with some households. Here it is evident that most consumers are running devices 24h without being switched off during the times the shops are closed.

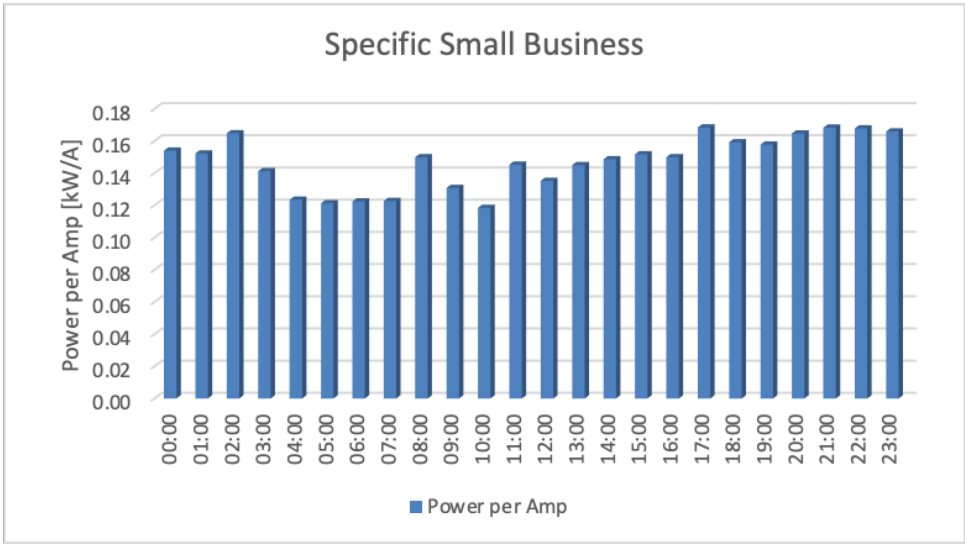


**Figure 9: Specific Power per Ampere Profile for Shops and small Business**

### 4.1.3 On public sector level

Within the camp assessment is also included the consumers and loads from schools, health centers and maternity centers. The demand and load profile were created based on the collected information and a measured load profile from a school with 400 students in the town of Khanke, KRI.

### 4.1.4 Sum Camp Profile

To evaluate different supply scenarios and ensure a proper supply system design it is essential to have a sum load profile.

The grid operator provided a daily power profile for the two medium voltage lines which feed the public grid-based electricity to the camp. The profiles show very similar characteristics for both feeders over a two year period. Figure 10 uses the data from the time period we measured the consumers in the camp to create a normalized sum power profile for Domiz 1. This profile allows the creation of a realistic load profile for the whole camp, by multiplying the daily seasonal normalized profile with the camp hourly values of each day.

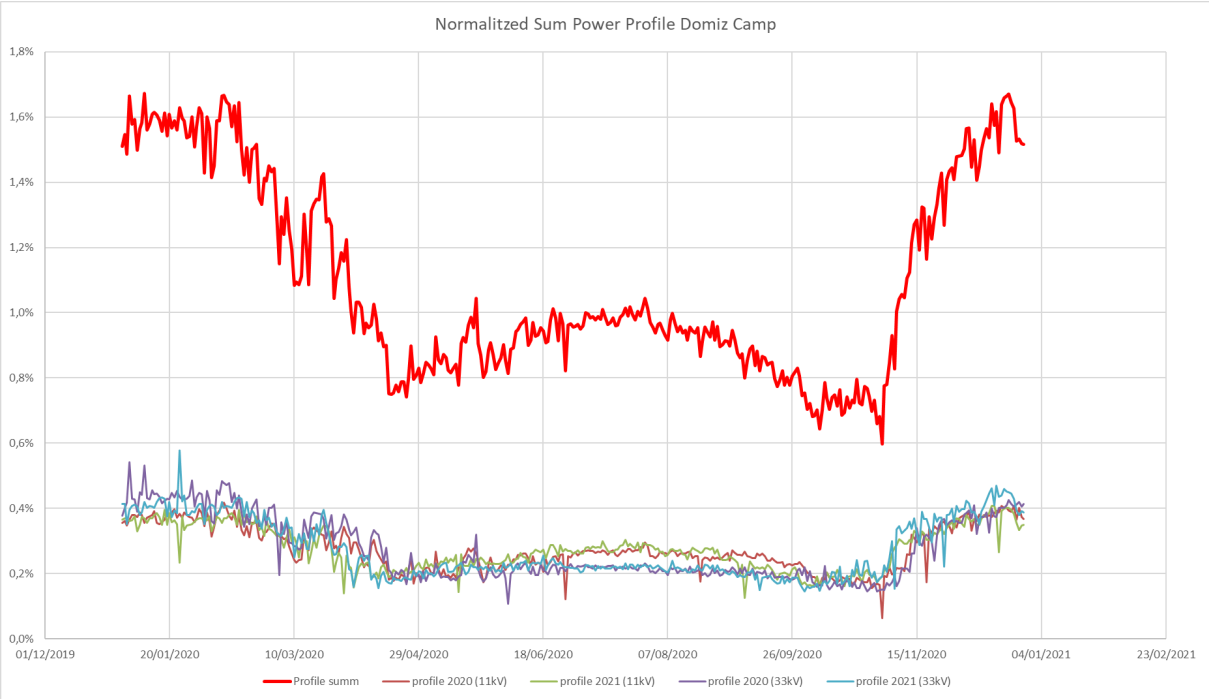


**Figure 10: Power Profile of medium voltage supply years 2020&2021**

The sum load profile is based on the following approximation:

- 5333 households with a circuit rating of 6A
- 556 small and medium businesses with an average circuit rating of 10A
- 44 daily operation facilities - e.g. school and health centers - with an average circuit rating of 25A

The load profile was adjusted for the different supply scenarios for the times when the grid was not available to simulate the community diesel supply with a factor 0.66 (equivalent to the consumers with a circuit rating of 4A instead of 6A).

Given the current situation that the grid is unavailable for about 50% of the time, with slight daily, weekly and seasonal variations, we can assume that the created load profile represents a valid total consumption should the grid be available for 100% of the time 24h over 365 days per year.

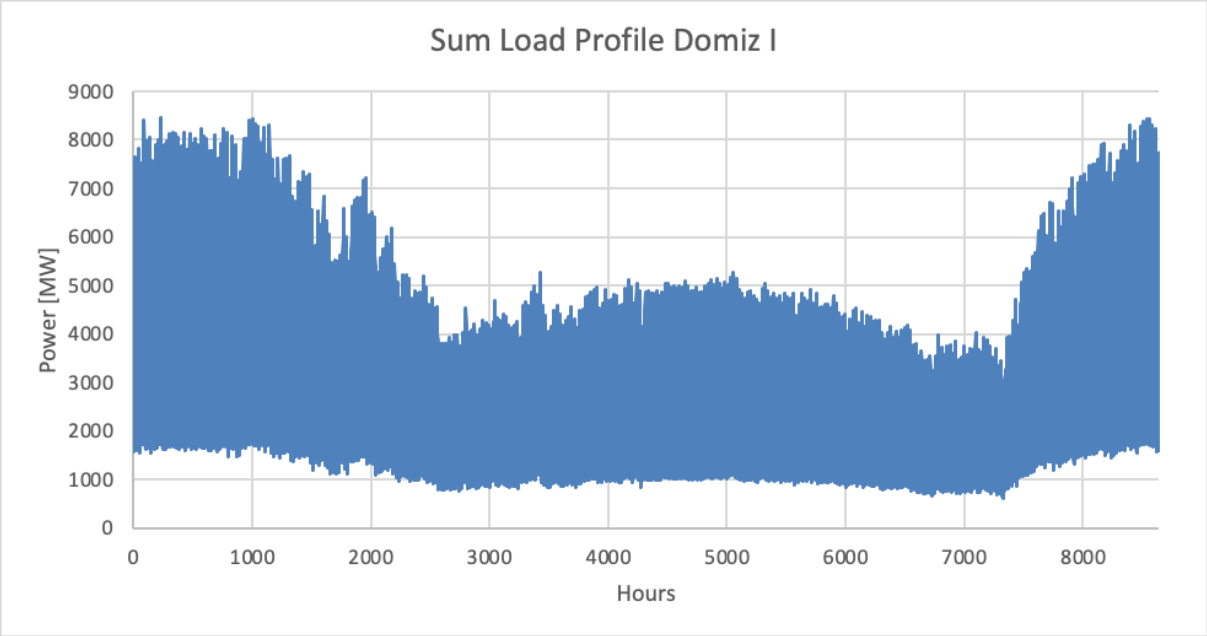


**Figure 11: 100% supply load profile from Domiz 1**

This profile was used to simulate the scenarios outlined in chapter 4.4

### 4.1.5 Energy efficiency & Consumer behavior

The energy measurement in early 2022 has shown that consumption in shops remained at the same level during the day and night. This indicates that the loads in the shops are not switched off outside the opening hours of the business. Significant energy savings and an increase in efficiency could be achieved by increasing awareness of the value of energy to motivate people to switch off loads whenever they are not needed.

A switch to highly energy efficient devices can make just as significant a contribution to emissions savings as the use of renewable energy sources. Motivation to upgrade devices is largely driven by the value the consumer places upon energy. If electrical energy is free whenever it is available, consumers are likely to buy cheap inefficient devices and let it consume whatever and whenever. LED-Lighting is a good example. An LED-light costs 5 to 10 times more than a classical Edison bulb and consumes 1/10 of the energy. A consumer that pays for energy is therefore much better off buying the LED-light. The discussion in the following chapter follows this logic and demonstrates possible interventions to stimulate energy efficiency.

**Winter heating**

The load profile of the whole camp shows a significant increase in power and energy - the increase from summer to winter is almost double. The only logical reason for this increase is electrical heating. Electrical heating is typically done with very inefficient electrical heaters, which are cheap and are widely available in the KRI at local markets. When the public grid is available these heaters are switched on to tackle the cold, however, when the households are warm the devices are not switched off because the grid can go off at any moment and the devices do not have a good temperature control. Due to insufficient insulation in the shelters

the temperature rapidly decreases when the heater is off. In summary, the heating is inefficient and creates a very high electrical demand.

Another area of inefficiency is that the current diesel generators - which would also run in scenarios B1 to D2 in winter - burn costly diesel with only 40% of the energy used in the form of electrical energy mostly to heat up the shelters. The thermal energy of about 50% gets lost in cooling the diesel generators.

A combination of changes can decrease the costly winter demand to a large extent (30% to 50%). These include:

- Insulation improvement of the shelters
- Building up a heat grid in the area of the diesel generators to use “waste heat” for heating the shelters. With the heat available from the diesel generators in B1 about 25% of the shelters can be heated with this energy.
- Using electrical infrared heater elements with room temperature control instead of the common electrical heaters, for the remaining 75% of shalters. Combined with a continuous electrical power supply a reduction of electrical winter demand could be reduced by 20% to 30%.

#### 4.1.6 Grid availability

The grid availability in the measured timeframe from January 20th to March 13th 2022 was 50.6% which means the public grid was on for about 12h per day. Grid availability during the day, changes based on the season. An assessment of grid availability in the Mam Rashan Camp close to Shirkhan in the KRI showed that the seasonal variation is about 10%. Intentional changes to the “grid schedule” could have an enormous impact on the capabilities of the solar electricity supply for the camp.

### 4.2 Overview of Solar Photovoltaic Plants and related Technologies

#### 4.2.1 Basic Principles of Solar Photovoltaic Plants

Solar PV plants use the global irradiation (GI), which is converted into electric energy. Adequate project locations in Dohuk, Iraq should offer at least 1600 kWh/kWp (energy output) per year. The basic concept of a PV power plant is shown below. The solar energy collected by the modules is aggregated in several steps until it reaches the inverter. The inverter converts the DC power provided by the modules into AC power to feed into the grid.

#### 4.2.2 Basic Principles of PV Modules

PV technologies differ primarily by the type of the manufacturing process, which leads to different price ranges, manufacturing cost and performance. PV technology is based on the photoelectric effect, in which the photons emitted by the sun get converted to electric power by the semiconductor. The semiconductor is typically made of silicon (85-90% of the global market).

These absorbed photons hit the atoms and thus are releasing electrons, which causes a chain reaction that multiplies the effect of electrons released. The electrons get lifted from lower potential to higher. This increase of potential results in the generation of current through potential difference (voltage). The reactions and release of electrons is continuous.

The purity level of the conductor material is important and that there are no gaps or defects at the molecular and atomic level of the semiconductor material. As a general rule, the less microscopic defects, the higher the efficiency of power conversion.

The efficiency of a solar cell (η) is the percentage of power from solar energy, incident on the panel, converted to electrical energy. This term is calculated using the ratio of the maximum power point of the cell, Pm, divided by the light power that reaches the cell, the global irradiance (E, in W / m²) and the surface area of the solar cell (Ac in m²).

$$\eta = \frac{Pm}{E\ x\ Ac}$$

As this efficiency varies in different irradiance conditions, the PV industry defined certain conditions for efficiency rating of PV panels. These are called standard test conditions (STC).

Another important standardized variable is the Normal Operating Cell Temperature (NOCT) for modules. This is a characteristic cell value defined as the temperature of the cells, which they reach at an irradiance of 800 W / $m^2$, an ambient temperature of 20°C and a wind speed of 1 m / s – typically given at open circuit.

Three main solar cell technologies are commercially available:

- Monocrystalline
- Polycrystalline
- Thin Film

**Monocrystalline Technology**

The manufacturing process of monocrystalline cells requires more effort in comparison to other technologies. However, these cells offer higher efficiency – typically within 15-22%.

Advantages:

- The loss of efficiency due to the higher temperature is lower than for other types of crystalline module technologies.
- Mature and commercially proven technology.
- Long lifetime of panels.
- Low degradation of maximum 0.1% - 0.5% per year (manufacturer guarantee is 0.7% degradation per year; however reality proves to be less).
- Lower installation costs.
- More environmentally friendly than other technologies; for example, some thin film technologies use cadmium. Monocrystalline cells are not harmful to the environment.

Disadvantages:

- The initial investment costs are higher.
- Higher risk of damages (micro cracks) compared to thin film during transport or during operation at sites with high wind speeds.

Based on the high risk of earthquakes in the region, it is not recommendable to use monocrystalline modules.

**Polycrystalline Technology**

This technology exists since 1981. The manufacturing process is simpler when compared with monocrystalline technology.

Advantages:

- Lower production costs.

Disadvantages:

- Lower efficiency, due to lower purity of the cell material: 14-18% (module size)
- Because of the lower efficiency, slightly more ground surface area is required to reach the same capacity (as for mono crystalline).
- Higher risk of damages (micro cracks) compared to thin film during transport or during operation at sites with high wind speeds.

*Polycrystalline modules are suitable for the site and are offering the best price-efficiency balance.*

**Thin Film Technology**

This technology is called Thin Film because only a couple nanometers of the semiconductor material is placed on a substrate material. Hence, a very low amount of material is needed. The main semiconductor materials in use are:

- Amorphous Silicon (a-Si)
- Cadmium Telluride (CdTe)
- Copper Iridium Gallium Selenium (CIS / CIGS)
- Organic photovoltaic cells

Thin Film technologies have a low market share, except for the CdTe material, with the main manufacturer First Solar. But also CIS / CIGS technologies are having an increasing market, because of their high efficiency. Depending on the technology, standard thin film module efficiencies have reached 7 - 15%. Prototypes of these technologies reach 16% and more which are expected to be transformed to standard products in the future.

Advantages:

- Easier to manufacture, thus lower costs.
- Stable structure (glass - glass)
- Less affected by high temperatures and shadowing.

Disadvantages:

- Faster degradation rate of up to 0.7% per year. However, there are some hints that nowadays CIS has degradation rates comparable to crystalline modules.
- Lower efficiency leads to greater surface area requirements, for the same capacity.

*Based on the limited available space at site, it is not recommendable to use thin film technology as CdTe.*

| | | Crystalline | | Thin Film | |
|---|---|---|---|---|---|
| | **Parameter** | **Monocrystalline** | **Polycrystalline** | **CdTe** | **CIS / CIGS** |
| 1 | Voltage rating –$V_{mp}$ and $V_{oc}$ | 80 % – 85 % | 80 % – 85 % | 72 % - 78 % | 72 % - 78 % |
| 2 | Temperature Coefficient | Higher losses (ca. -0,4 %/K) | Higher losses (ca. -0,45 %/K) | Lower losses (ca. -0,2 %/K) | Higher losses (ca. -0.35 %/K) |
| 2a | Performance Losses for 40°C ambient temperature (~ 60°C cell temperature) versus STC conditions (25°C cell temperature) | ~ 14 % | ~ 15.75% | ~ 7% | ~ 12.25% |
| 3 | I-V curve Fill Factor | Higher<br>70 % - 85 % | Higher<br>70 % - 85 % | Lower<br>60 % - 72 % | Higher<br>70 % - 85 % |
| 4 | Module Construction | Framed with structural or anodized aluminum | Framed with structural or anodized aluminum | Normally Frameless | Normally Frameless |
| 5 | Module Efficiency | 14 % - 20 % | 12 % - 17 % | 6 % - 12 % | 13 % - 15 % |
| 6 | Inverter Compatibility and Sizing | High efficiency<br>□ less modules<br>□ less inverters | High efficiency<br>□ less modules<br>□ less inverters | Low efficiency<br>□ more modules<br>□ more inverters | High efficiency<br>□less modules<br>□ less inverters |
| 7 | Mounting System | Industry Standard practices | Industry Standard practices | Special clips and structures for frameless modules may be needed to hold the module.<br>Mounting system has to be accepted by module manufacturer. | Special clips and structures for frameless modules may be needed to hold the module.<br>Mounting system has to be accepted by module manufacturer. |
| 8 | Layout Area | Much smaller size for the same output. | Smaller size for the same output. | May require up to 50% more space for the given project size. The extra space can't be standardized and depends on the design (rows over each other) and the site conditions. | Smaller size for the same output. |

| | | Crystalline | | Thin Film | |
|---|---|---|---|---|---|
| | **Parameter** | **Monocrystalline** | **Polycrystalline** | **CdTe** | **CIS / CIGS** |
| 9 | Applications | On grid and off grid usage.<br>More usual as a reference cell and used for scientific tests. | On grid and off grid usage. | On grid and off grid usage. | On grid and off grid usage. |
| 10 | PV Plant cell cost | More expensive than polycrystalline and CdTe modules due to high cell efficiency | Cost Higher than CdTe due to higher cell efficiency; Production process easier which lowers the basic cost | Cost Lower due to lower efficiency and double pane glass sheeting | Very expensive up to now |
| 11 | PV Plant module unit cost | Cost per kWp slightly higher as for polycrystalline modules, but comparable to the cost per kWh due to fewer losses | Cost per kWh comparable | Cost per kWp slightly higher as for polycrystalline modules, but comparable to the cost per kWh due to fewer losses | Cost per kWp slightly higher as for polycrystalline modules, but comparable to the cost per kWh due to fewer losses |
| 12 | PV Plant total cost | Lower Cost due to higher efficiency of the modules (less modules and less mounting Structures).<br>Entire cost depends on the market situation (module price) and the concerned country (m² cost) | Usually lowest cost (low m² cost and less m² needed because of the higher efficiency compared to thin film modules).<br>Entire cost depends on the market situation (module price) and the concerned country (m² cost) | Highest cost due to additional space and mounting structures needed.<br>(Entire cost depends on the market situation (module price) and the concerned country (m² cost) | High cost due to additional space and mounting structures needed.<br>Entire cost depends on the market situation (module price) and the concerned country (m² cost) |
| 13 | Module power output | Immediate and stable; but zero shadow tolerance, high losses when temperature high and irradiation suboptimal | Immediate and stable; but zero shadow tolerance, high losses when temperature is high and irradiation suboptimal | Requires time to stabilize power output; even slightly shadowed output is feasible | Very good weak light performance (best results of the technologies in winter) |
| 14 | Degradation | Around 0,3 % per year | Around 0,3 % per year | Around 0,4 % per year | Around 0,2 % per year |
| 15 | Market perspective | Standard technology, many providers | Standard technology, many providers | One big provider (First solar) | Little number of providers, new technology (2009) |

**Table 7: comparison crystalline/ thin film PV plants**

*Based on the costs and the availability on the market it is usually recommended to go with the standard technologies polycrystalline and CdTe modules. Based on the limited space availability it is recommended to go with polycrystalline modules.*

### 4.2.3 Basic Principles of Storage Systems

Batteries are characterized through the capacity (kWh or Ah) and the C-Rate.

The capacity gets labeled as a nominal capacity by the manufacturer, but how much energy can be truly stored and extracted in and from the battery is dependent on the technology. But even within the same technologie, manufacturers give differing guidance on the effective capacity.

The C-Rate represents the value of how much power can be drawn from a battery per its nominal capacity. For example a battery with a C-Rate of 0,5 and a capacity of 10kWh can provide maximum power of 5kW.

**Battery storage on the basis of lead**

The most commonly used type of battery in the past was the lead accumulator. The main reasons for using lead accumulators were the low price per amount of storable energy attainable, the low self-discharge and the comparatively high efficiency of about 80% for a roundtrip. The losses in lead-acid batteries can be explained in part by the gas detonating during charging. The vapors are reduced with maintenance-free lead-gel batteries. Solar lead-acid batteries differ from other lead-acid batteries in their inner mechanical construction; they are optimized for particularly long service life cycles and behavior in deep discharge. Typical cycle numbers are 1200 of up to 80% discharge depth. Maintenance-free lead-gel batteries have the advantage that no or only a minimal acid stratification is formed, accepting that considerably low cycle numbers will result. An additional circulation of acid prevents the acid stratification in lead-acid batteries completely. This is of importance mainly in stationary operation.

Lead-acid batteries can be produced also in a closed form, which can be operated independent of any position. These include the VRLA batteries. The acid is tied in glass fiber mats (AGM, Absorbing glass mat) or with silica gel. As these types of batteries in principle have no openings, the absorption voltage during the charge must not be reached.

**Battery storage on the basis of lithium**

Lithium-ion batteries are the generic term for a number of different chemical systems, which differ among others due to the composition of the cathode, the anode and the electrolyte.

Lithium-ion batteries developed over the past 5 years to be the source of solar batteries, which is caused by the considerably fallen price of lithium-ion batteries and technical improvements especially in the electrolyte. Also lithium-ion batteries partly have a very high cycle stability of more than 10,000 charge / discharge cycles and a long lifetime of up to 20 years. In particular also lithium iron phosphate batteries are used, which are characterized by a high cycle stability, high reliability and low price.

There are - as in any accumulator - energy losses due to the resistance of both the loading and unloading. Typical overall efficiency is up to around 95% for a roundtrip. If small charge and discharge currents are used in relation to the maximum current carrying capacity of the battery, over 98% can be achieved.

The power density is typically 300-1600 W/kg. Lithium-ion batteries have a high specific energy compared to other battery types; however, they require electronic protection circuits in most applications. The energy supply is very short notice. The Lithium-Ion cells have to be cooled or heated to provide optimal conditions for the chemo electrical process. High temperatures can lead to significant reduction in the cycle time, therwith in the lifetime of a battery.

Most modern batteries are typically a sealed device that needs minimal to no maintenance throughout its lifetime.

Large lithium-ion battery systems are also used in battery-storage power stations. Lithium-ion batteries are the market standard for the storage of within PV-Hybrid systems. Therefore it is recommended to use those batteries for the system.

### High-temperature Batteries

A sodium-sulfur battery, abbreviated as NaS, is a type of rechargeable battery, a so-called secondary cell. Compared with other types of battery, a solid electrolyte and liquid electrodes are used instead of a liquid electrolyte. High operating temperatures in the range of 270 to 350 ° C are required for operation. It belongs to the Group of thermal batteries thus.

Sodium-sulfur batteries have, in addition to the benefit that the essential basic materials such as sodium, sulfur and aluminum are readily available, a comparatively high storage density in the area just above 200 Wh/kg.

In contrast to many other rechargeable batteries, the NaS cell has a very low electrochemical self-discharge, the efficiency between charge and discharge is in the area of 70 to 85%. The virtually non-existent electrochemical self-discharge is however relativized, as the cell must be kept in a high temperature range from about 300 to 350°C to maintain the operability, which requires additional heating systems in addition to an appropriate thermal insulation to the cooler environment. If this heating energy necessary for the operation is attributed to the self-discharge or if the power is taken from the battery system, a high total self-discharge is existent for small systems due to its high specific surface.

As with all systems, where thermal losses should be reduced, small NaS batteries are suitable only for short-term storing of energy. With super insulated or very large NaS cells the efficiency can be greatly improved, as thermal losses theoretically are minimized.

The number of charge and discharge cycles is large compared to other battery types, but heavily dependent on the discharge depth. If the battery in each cycle unloaded is only very low, this corresponds to a considerable reduction of the effective capacity, some 10,000 cycles are possible. However, if a discharge occurs up to 10% before a new charge, the number of possible cycles before failure is reduced to some 1000.

### Redox-Flow batteries

The redox-flow battery (RFB) is an embodiment of a battery as electrochemical energy storage. It stores electric energy in chemical bonds, which are the reactants in a solvent in dissolved form. The two energy-storing electrolytes circulate in two separate circuits, between those the exchange of ions takes place using a membrane in the galvanic cell. In the cell, the dissolved substances are chemically reduced or oxidized, where electrical energy is released.

Compared to a battery without mass transfer a more elaborate construction exists, which requires at least two pumps for the circulation of the electrolytes, together with the necessary control and control devices, in addition to tank and piping. Therefore flow batteries are not so well suited for small consumers; the use in the area of Electromobility is subject of research. The most widely used and most important type of flow battery is the vanadium redox flow battery. In addition, there are other types such as the sodium bromide battery, zinc-bromine battery, iron-chromium battery and uranium battery.

Because the chemical compounds are dissolved in solvents separate from the cell and stored in any large tanks, the amount of stored energy is not dependent on the cell size. As a result, output power and storage capacity are separately scalable. The redox-flow battery is related with the fuel cell, but also with the batteries due to the electrochemical reversibility.

Depending on the size and type, the redox flow cells can provide some 100 Watt to several megawatts of power and have an efficiency in the range of 75% to 80%, while the power required for the necessary pump operation efficiency affects lowering. Furthermore, the system has a low self-discharge and a long service life. The latter is based on the fact that

the electrode material at the reaction of the electrolyte itself does not chemically react and thus does not degenerate. In contrast, the energy density is relatively low, about 25 Wh per liter of electrolyte are usual in vanadium redox battery sulfate based, to achieve approximately 50 Wh per liter electrolyte based on bromide.

For comparison: diesel fuel has an energy density of approximately 10 kWh per liter, that is about 400 times of the electrolyte of vanadium redox batteries; conventional lead-acid batteries achieve around 42 Wh/kg energy density, relative to the entire mass of the battery. Based only on the electrolyte of the lead battery, which approximately accounts for 50% of the battery, a calculated value of 80 Wh per liter electrolyte in a battery can be calculated.

### Fuel Cells

A fuel cell is a device that converts the chemical energy from a fuel (hydrogen) into electricity through a chemical reaction with oxygen or another oxidizing agent. There are many types of fuel cells, but they all consist of an anode, a cathode and an electrolyte that allows charges to move between the two sides of the fuel cell.

Hydrogen produced from the steam methane reforming of natural gas is the most common fuel, but for greater efficiency hydrocarbons can be used directly such as natural gas and alcohols like methanol. Fuel cells are different from batteries in that they require a continuous source of fuel and oxygen/air to sustain the chemical reaction whereas in a battery the chemicals present in the battery react with each other to generate an electromotive force (emf). Fuel cells can produce electricity continuously for as long as these inputs are supplied.

Fuel cells are used for primary and backup power for commercial, industrial and residential buildings.

Fuel cells are generally between 40–60% energy efficient.

The current developments use fuel cells in closed systems of electrolysis to produce hydrogen, and fuel cells to produce electricity as a long term storage for renewable energy coming from wind or solar plants. First commercial systems are available in the market with round trip efficiency of about 45%. This technologie is foreseen to replace diesel backup in the next 10 years.

### Pump Storage

Pumped-storage hydroelectricity (PSH) is a type of hydroelectric energy storage used by electric power systems for load balancing. The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power. Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest.

Pumped storage is the largest-capacity form of grid energy storage available, and, as of March 2012, the Electric Power Research Institute (EPRI) reports that PSH accounts for more than 99% of bulk storage capacity worldwide, representing around 127,000 MW. PSH reported energy efficiency varies in practice between 70% and 80%, with some claiming up to 87%.

The technique is currently the most cost-effective means of storing large amounts of electrical energy on an operating basis, but capital costs and the presence of appropriate geography are critical decision factors.

The relatively low energy density of pumped storage systems requires either a very large body of water or a large variation in height. For example, 1000 kilograms of water (1 cubic meter) at

the top of a 100 meter tower has a potential energy of about 0.272 kW·h (capable of raising the temperature of the same amount of water by only 0.23 Celsius = 0.42 Fahrenheit). The only way to store a significant amount of energy is by having a large body of water located on a hill relatively near, but as high as possible above, a second body of water. In some places this occurs naturally, in others one or both bodies of water have been man-made. Projects in which both reservoirs are artificial and in which no natural waterways are involved are commonly referred to as "closed loop".

Pumped storage plants, like other hydroelectric plants, can respond to load changes within seconds. It is particularly likely that pumped storage will become especially important as a balance for very large scale photovoltaic generation.

Long-term construction periods and the often required intervention in nature are disadvantages of the use of pumped storage plants.

### 4.2.4 Mounting structures and tracking systems

The photovoltaic panels can be installed on fixed structures or on moving structures tracking the sun. Trackers can be implemented either as a single-axis system or as a dual-axis tracking system.

**Fix mounted structure**

Fix mounted structures are usually tilted to face south (north in southern hemisphere) with a fixed angle depending on several parameters like for example the geographic location, power density, load profile, economics. Nowadays more and more PV power plants are installed with modules tilted to west and east, usually with angles between 10° to 15°. This installation type would offer lower peak capacity, however the generation curve would be less spiked and allow an energy generation distribution to be more equal over the day. The row shading of such installations is less, such that the rows can be installed closer to each other and more modules can be installed on the same area as it is possible with modules facing south. Depending on the construction the installation costs of west-east installations often are lower as with south oriented systems.

**Figure 12: PV plants**

For the location Dohuk, Iraq the optimal tilt for the module directed to South is 32°. With this angle the highest irradiation into the module plane can be achieved for an unshaded module. The transposition factor (FT) is 1.15. The transposition factor is the ratio between solar irradiation on tilted versus horizontal surface.

### Tracker systems

The aim of trackers is an optimized adjustment of the module surface to the sun during the day to increase the total of irradiation into the module plan. This can also lead to a greater efficiency in converting solar energy.

Dual axis tracker follows the sun in azimuth and tilt. The sun can be exactly tracked over the course of the day to achieve an optimized irradiation angle. Dual axis trackers have one pole which is carrying and tracking a frame with modules mounted on. The installed module capacity on the plant has to be lower than with fixed mounted structures to avoid overwhelming shading losses (15-25 Wp/m$^2$ instead of 50-75 Wp/m$^2$). Dual axis trackers are almost independent of the landscape.

The transposition factor for a two axis tracker for the location is 1.35 and therefore 132% of that of the fixed plane's optimum.

**Figure 13: plants with tracker system**

One axis tracker usually follows the azimuth of the sun. Several construction types exist. One is similar to a dual axis tracker with one pole carrying a module frame (vertical axis system). In that case the module tilt is fixed and the pole is used as a rotation axis. The tilt depends on the location. For the location Dohuk, Iraq the optimal installation has a tilt of 20° for the module directed to the South.

Because the one axis tracker described above needs similar space as dual axis tracker nowadays another type of one axis tracker is in use. This one has a horizontal rotation axis oriented from south to north or from east to west. The modules are installed parallel to the rotation axis. Depending on the way of installation and length of the horizontal axis the requirements to the flatness of the area can be higher, because the horizontal axis itself is not able to compensate for irregularities. The one axis tracker with the east-west axis has a transposition factor of around 1.09 whereas the tracker with north-south axis has a transposition factor of 1.29 or 132% of that of the fixed plane's optimum.

**Figure 14: PV plants along horizontal axis**

The decision to choose any of the three types of mounting structure is based on a technical and economic evaluation. When choosing a tracking system, the extra energy generation in combination with the energy price must be compared to the additional investment and maintenance costs required for tracking systems.

In general tracker solutions gather more irradiation per installed module capacity than fixed mounted modules. The peak of the production curve is wider during the day as that of fixed mounted modules. But the installation effort is higher for tracker solutions and significantly more maintenance is required for the moving parts in a tracking system. More attention has to be laid into the resistance against heavy storms.

| | **Parameter** | **Fix-tilted** | | **Horizontal single-axis tracker** | | **Vertical single-axis tracker** | **Dual-axis tracker** |
|---|---|---|---|---|---|---|---|
| | | **South faced** | **East-west** | **East-west** | **North-south** | | |
| 1 | System costs | Lower than for tracker solutions, as no mechanical parts | | Higher costs than fixed-tilted. High differences between the manufacturers.<br>Higher costs than fixed-tilted. High differences between the manufacturers. | | Higher costs than horizontal tracker | The highest costs of all systems |
| 2 | Installation costs | Lower than for tracker solutions, as less complex system. But the difference regarding the total installation cost is minimal compared to the horizontal tracker. | | Higher costs than the fixed tilted system, but lower than the vertical tracker.<br>Higher costs than the fixed tilted system, but lower than the vertical tracker. | | Higher installation cost, especially for the commissioning phase. | Higher installation costs, especially for the commissioning phase |
| 3 | Maintenance costs | Lower than for tracker solutions, as no mechanical parts | | Depends on the selected manufacturer (options without mechanical parts available), but cost higher than fixed-tilted | | Higher costs based on the mechanical parts | Higher costs based on the mechanical parts |
| 4 | Transposition factor | 1,14 | 0,99 | 1,23 | 1,18 | 1,22 | 1,31 |
| 5 | Max. pivoting angle range | Fixed in between 20° to 35° | Fixed in between 10° to 20° | -120° to 120° | -120° to 120° | Fixed tilt for site, 0° - 25°, vertical axis -120 to 120° | Motorized tilt 00-80° and vertical axis -120° to 120° |
| 6 | Site requirements | System is adaptable to uneven ground and high slopes. Standard system up to 35°(North/South) and 10°(East/West) | | Ground might be uneven with slopes up to 28° | Ground might be uneven with slopes up to 28°<br>The system makes just sense if the site is not facing South. | Ground might be uneven but sites with higher slopes are not suitable without huge extra effort | Ground might be uneven but sites with higher slopes are not suitable without huge extra effort |
| 7 | Space requirement | Several rows can be installed over each other. Space | No row shading, so the rows can be installed near each other. Best | Installation of rows over each other is limited, but space requirement | Installation of rows over each other is limited, but space requirement | The distance between the trackers must be high. Space requirement is high | The distance between the trackers must be high. Space requirement is high |

| | Parameter | Fix-tilted | | Horizontal single-axis tracker | | Vertical single-axis tracker | Dual-axis tracker |
|---|---|---|---|---|---|---|---|
| | | South faced | East-west | East-west | North-south | | |
| | | requirement low | space requirement | not much higher than fixed- tilted | not much higher than fixed- tilted | | |
| 8 | Space factor (Wp/m2) | ~50 - 75 | ~60 - 90 | ~40 - 65~ | ~45 - 55 | ~15 - 25 | ~15 - 25 |
| 9 | possible MWp on site | ~ 14 – 20 | ~ 18 – 25 | ~ 12 – 16 | ~ 13 – 15 | ~ 5 – 8 | ~ 5 – 8 |

**Table 8: comparison of different tracker systems for PV plants**

Based on the costs, the energy yield and the limited space available on-site it is recommended to go with a south faced fixed tilted or an east-west tilted mounting structure.

### 4.2.5 Inverter Technology

Because PV panels generate DC electricity, it must be converted to alternating current before it can be fed into the grid. This is achieved by an electronic device called an inverter.

State of the art inverters offer a broad range of operational stages, which generally fulfill all the requirements of the international grid codes in terms of fault-ride-through and reactive power provision. Inverter stations provide a protective shell in which PV-strings can be connected to inverters. Centralized inverters typically have a capacity from 500 kWp to 2 MWp of DC PV-Power.

From the inverter stations the AC power is stepped-up by a MV or HV-Transformer, and then connected to a medium or high voltage grid.

Regarding the inverter system two design types can be selected: a central and a decentralized design.

**Central inverter**

Central inverters are standard in MW PV plants. The strings are combined in string combiner boxes and several combiner boxes are connected to an inverter. Typically the output power of central inverters is between 500 kWp and 2 MWp. The inverter can be installed in a compact station, in a container or as an outdoor system depending on the space for installation and the transport opportunities.

Typically central inverters have a better price per MW, but they require a specific training of the electricians for the commissioning procedure, in case of failures and repair.

The efficiency is around 1% higher than that of string inverters.

**String (decentralized) inverter**

String inverters are commonly used in smaller sized PV plants but there is a trend to use them also in large scale PV plants. The strings are connected directly to an inverter, which are typically up to 100 kW.

String inverters can be installed and exchanged by basic educated electricians and spare parts can be stored near the side. The inverters are easy to transport and handle. In complex terrain with a lot of shading the benefit is that less module strings and therefore fewer modules are combined per inverter. Such in the case of partial shading of the PV generator the mismatch losses are less because fewer modules are affected.

*Based on the uneven ground and lack of trained electricians it is recommended to go with a decentralized string inverter system.*

#### 4.2.6 Control System

A PV plant typically is controlled by a SCADA System (Supervisory Control and Data Acquisition) and can remotely be managed and supervised. SCADA systems are typically blended with the monitoring system to provide information on the status of the components and electrical and environmental data.

The control interface is in many cases established to the control room of the grid operator or to the power dealer in case of energy sales to third parties in the open energy market.

In the Dohuk grid it is recommended to establish a secure control interface to the grid operator in the next substation with control room, which will allow the operator to change grid supporting parameters and curtail the plant in oversupply situations.

## 4.3 Site Description and Assessment

#### 4.3.1 Geographic Parameters

The PV plant will be installed within the Domiz Camp. The whole camp site is rented by UNHCR from the Duhok Governorate and it has been agreed with UNHCR that the following two sites will be available for an installation of the PV plant.

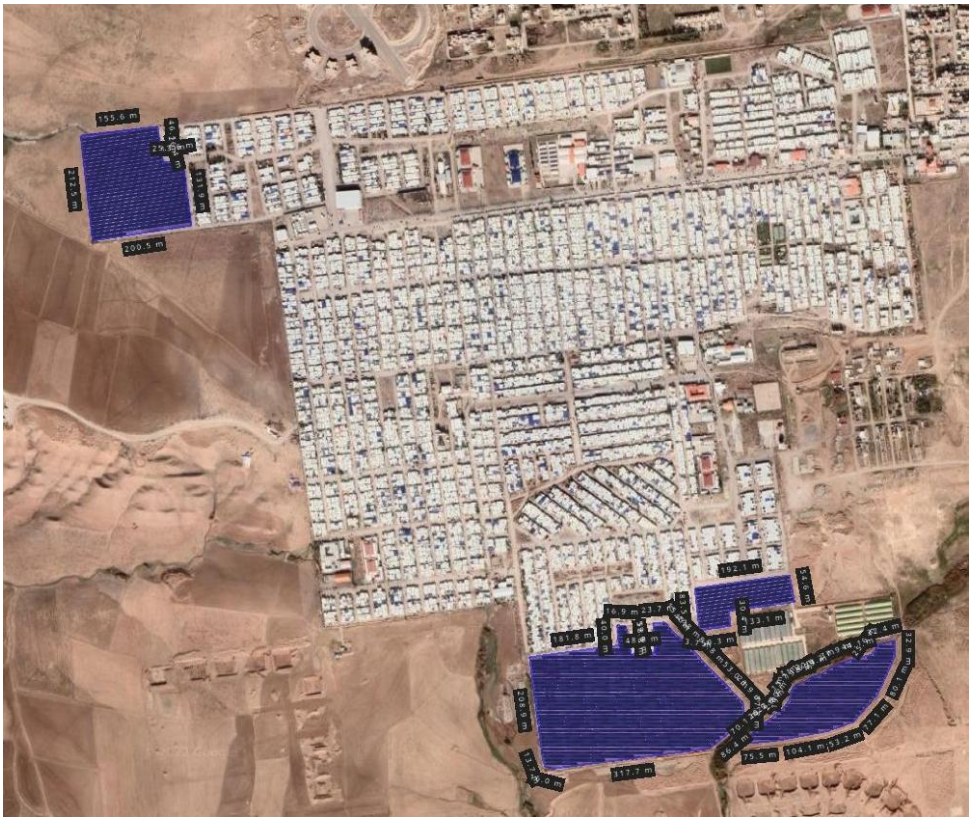

**Figure 15: Domiz Camp with solar plants**

### 4.3.2 Climatic Conditions

The average annual temperature is 20°C however temperatures vary considerably, reaching below freezing in the winter and up to 50°C in the summer. The coolest month of the year is January with an average temperature of 4.8°C with July the hottest month of the year with an average of 34.4°C. The wind speed in summer and winter between 2.5 and 3 m/s

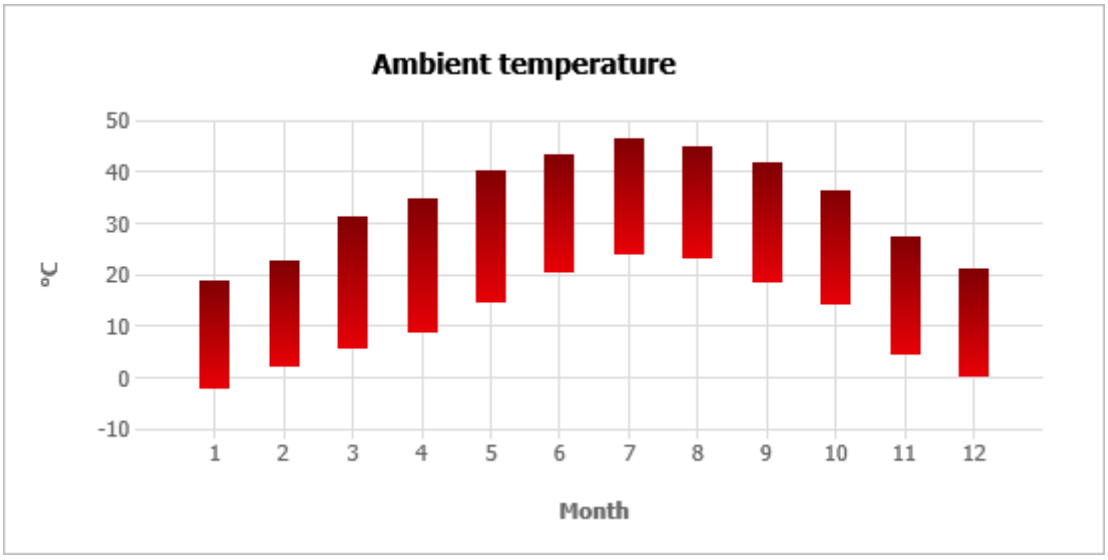


**Figure 16: ambient temperature in the region over one year**

### 4.3.3 Other Environmental Aspects

In 2021, Duhok was shaken by 3 earthquakes of magnitude 4.0 or above, 8 earthquakes between 3.0 and 4.0, and 42 earthquakes between 2.0 and 3.0. There were also 3 earthquakes below magnitude 2.0 which people don't normally feel. This needs to be considered in the statics of the mounting structure and was taken into account when determining the construction costs. The risk of damage to the power supply system is rated as minimal.

Flooding might also pose a problem, as an increase of heavy rainfall has occurred over the last few years. This needs to be considered in the statics of the mounting structure and was taken into account in the construction costs.

### 4.3.4 Topography and Grounding

The smaller potential PV site is very even and will not require massive earthworks.

The potential area in the south contains some old concrete foundations of demolished buildings and will require earthworks to levelize the ground for installation. In general the soil is sandy and requires deep foundations. The additional costs are considered in the economic scenarios.

### 4.3.5 Meteorology

High temperatures during the summer need to be considered for the electronic equipment and the overall design. Not all electronic components are rated for an ambient temperature of 50°C. Cooling systems for the batteries need to be considered for adequate lifetime. It is preferable to choose module technologies with lower temperature coefficient.

### 4.3.6 Transport Access

Dohuk 1 is easily accessible via main roads and the potential PV sites within the camp are also accessible for trucks and construction machinery. No extra costs are required for the development of access roads. The import of equipment is easily possible via the nearby airport of Erbil in KRI, the harbor Mersin in Turkey or directly by truck from Europe.

### 4.3.7 Water Access

Dohuk 1 has five boreholes for the water supply of the camp. The capacity of the boreholes is big enough to cover the water demand within the camp. Nevertheless, water scarcity is an increasing problem in the KRI and region generally. Therefore, it is important to implement a highly efficient cleaning system for the modules. Based on the dusty environment the cleaning of the modules will be required every 3 months. It is recommended to install water tanks to collect rainwater for the cleaning of the modules. Those costs are covered within the O&M costs.

### 4.3.8 Grid Access

The Domiz I Camp is supplied through two different feeders: one is an 11kV-Feeder and one is an 33kV-Feeder. The 11kV-Feeder is solely for the supply of Domiz 1. The 33kV-Feeder supplies a part of Domiz 1 and Domiz 2.

| | # 250kVA Transformer | # 400kVA Transformer | Transformer Capacity [kVA] | Share |
|---|---|---|---|---|
| 11kV-Feeder | 19 | 8 | 7700 | 43% |
| 33kV-Feeder | 0 | 26 | 10400 | 57% |

**Table 9: Features of the feeders for Domiz 1 and Domiz 2**

**Figure 17: Grid overview Domiz 1&2 with two different voltage level feeders**

The possible locations for the PV-Arrays are less than 50m away from possible grid access points.

If the grid in the camp Domiz 1 will continue to have two medium voltage feeders the supply systems would need to be divided between these.

The supply systems would be connected via single transformers to the different voltage levels. As the share of the supply capacity between the two feeders is almost 50%, the supply systems would also need to be divided by half.

To keep the Domiz 2 camp on its typical grid schedule the 33kV-Feeder would need to get a remote operational bypass.

In discussion with the grid operators they proposed that changing the setup to one feeder per camp could be a possible option. In this case the 33kV-Feeder would feed Domiz 1. This would allow a simpler grid connection of the supply system and more flexibility to change grid schedule for the camp without influencing the adjacent loads.

## 4.4 Plant Layout and Description of Technical Equipment

### 4.4.1 Power Supply Infrastructure

Current Status

Today the camp is powered by a public grid (medium voltage) and a community diesel (low voltage) grid infrastructure. The parallel infrastructures are combined through a changeover in the households.

- The public grid supplies about 14,096 MWh to the camp.
- The community diesel supplies about 10,502 MWh to the camp.
- The households typically have a 6A supply over the public grid and choose additionally a 4A supply over the community diesel generator. The assumption is that a similar ratio between public grid supply and community diesel supply for shops
- Total consumption is 24,598 MWh

Small generators to substitute the grid outages besides the community diesel were not considered.

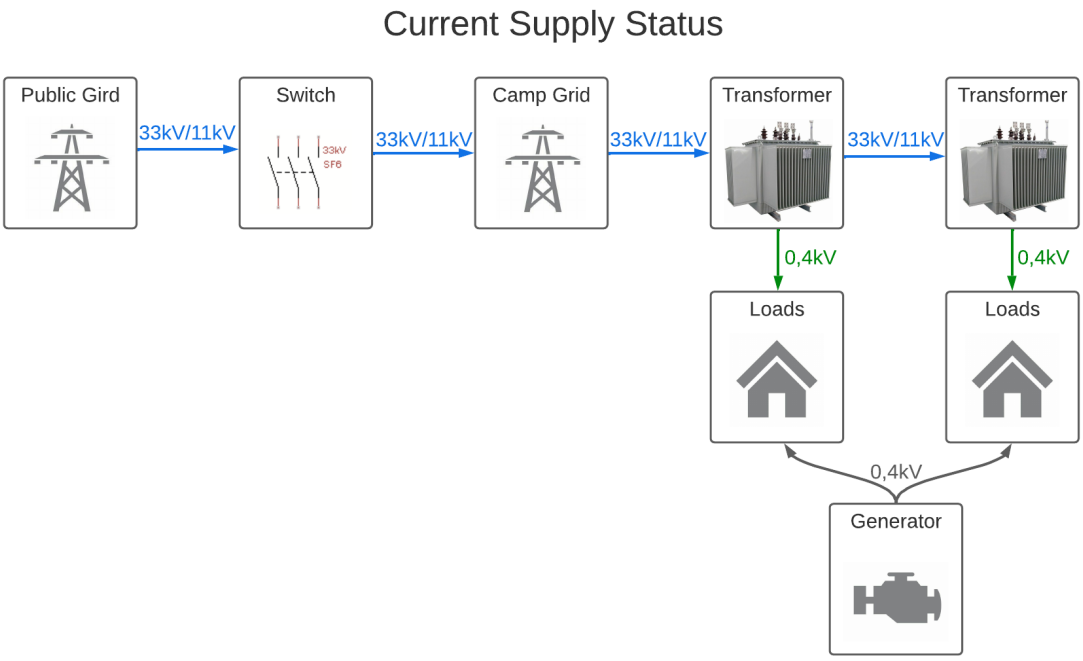


**Figure 18: Block Diagram of current supply situation in the Camp**

Variants of Supply

The supply infrastructure is dependent on multiple technical, political and economic aspects.

- Available space for PV-power plant (land capacity)
- Using existing power distribution infrastructure versus building up parallel power distribution infrastructure
- The grid schedules
- Complexity of the grid infrastructure
- Supply security (keep status, improve status, decrease status)
    - All time 6A for the households

- Grid with 6A and alternative with 4A as an approximate assumption (like today only substitute diesel with hybrid system)

Taking into account the above considerations and seeking to cover the most feasible variants/options the following 8 scenarios are reviewed further in this study.

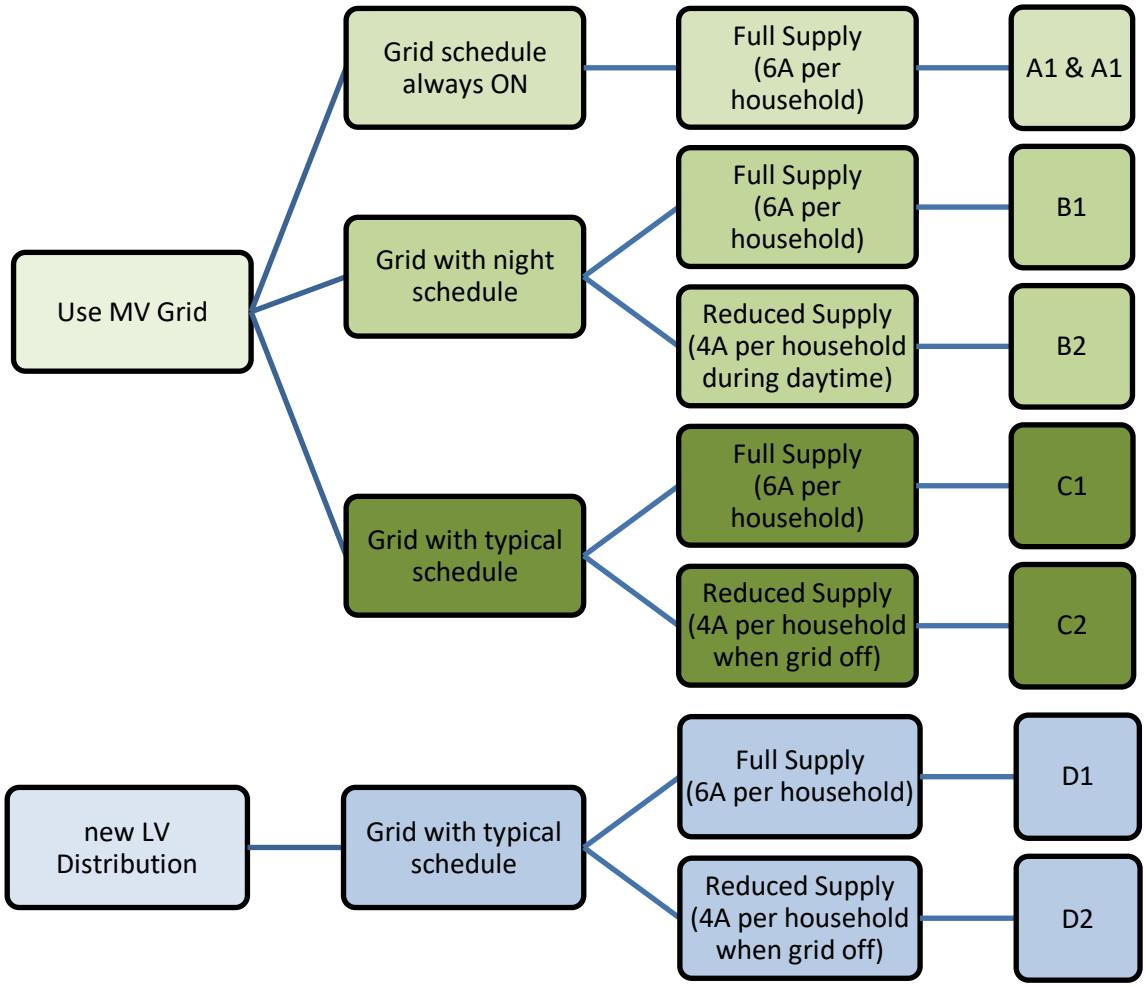


**Figure 19: explanation of the 8 scenarios**

Photovoltaic Capacity

The land available within the fence of the Domiz 1 camp is sufficient for an electrical DC capacity of about 16.6 MWp.

To derive the PV capacity the following moderate assumptions are considered:

| | |
|---|---|
| Module efficiency | 20% |
| Tilt Angel | 15° |
| Shading Angle | 19° - resulting into 2% shading loss |

**Table 10: photovoltaic capacity**

The available land within the camp is flat and unshaded and is therefore highly suitable for the installation of a PV-power plant. The possible areas are in the northwest and in the south of the camp. The blue hatched areas in Figure 20 are the identified PV-arrays.

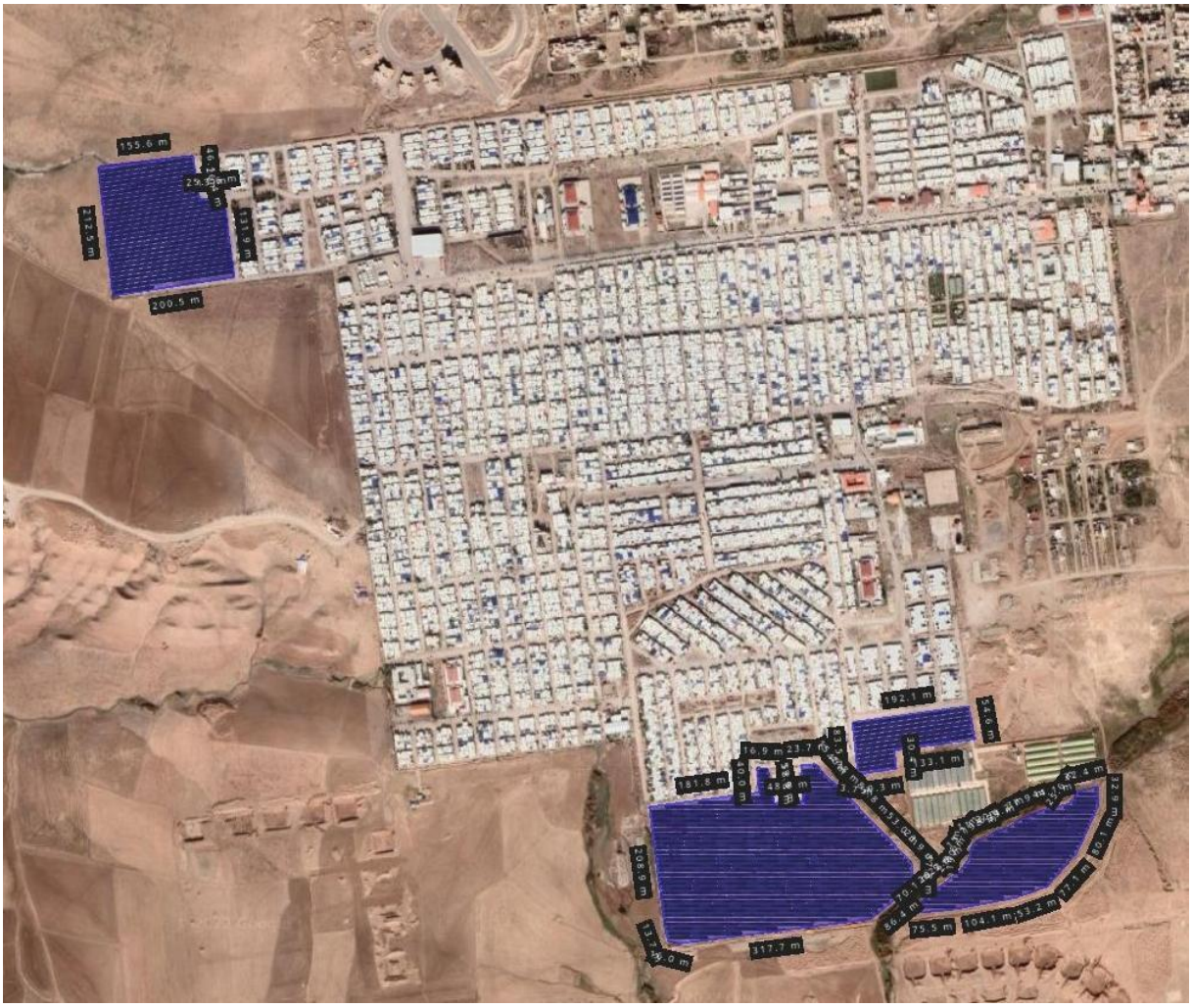


**Figure 20: Map for photovoltaic suitable land within the camp Domiz I**

The available space is adequate for the above-described variants A1 to D2.

### 4.4.2 Power Plant Technology Configurations

- **PV-Power Plant**

Every case includes a ground mounted PV-power plant with a capacity of between 7 MWp and 16 MWp. The simulations were processed based on standard modules from commercial mass production established quality manufacture, with an area efficiency of 20%, which represents the current status of module technology in mass production.

The system is designed with string inverters mainly for maintenance and repair advantages, as local electricians can handle the service and replacement of string inverters. The AC side of the inverters is collected on low voltage level and connected to a medium voltage substation. The two locations have separate transformer substations to reduce the length of low voltage cable.

- ## Battery System

For the variants B1 to D2 a battery backup system with black start capabilities is required. Dimension of the battery inverter is on the level of the peak power minus the needed diesel backup power, so that the battery system and diesel backup can provide more power than the maximum peak of the camp demand. The battery energy capacity is designed to cover about 5 hours of the typical camp energy demand, to allow continuous supply of the camp. Lithium iron phosphate (LFP) batteries with a c-rate of 1 are selected for the system. The capacity size in Table 11 is related to the nameplate capacity - the executable capacity considered in the simulation is between 4…10% lower than the nameplate value for the LFP technology.

| | | Use MV Grid | | | | | | New LV Distribution | |
|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical Schedule | |
| Source | Unit | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| PV-System | Power/MWp | 16.6 | 6.9 | 11.5 | 6.9 | 11.5 | 6.8 | 11.5 | 6.9 |
| Battery-System | Power/MW | - | - | 6.0 | 4.0 | 6.0 | 5 | 6.0 | 4.0 |
| | Energy/MWh | - | - | 8.4 | 5.6 | 8.4 | 5 | 8.4 | 5.6 |
| Supply by PV/ESS | Energy/MWh | 14,035 | 10,816 | 14,184 | 9,996 | 6,270 | 5,291 | 6,676 | 4,676 |
| Diesel Power | Power/MW | | | 4.0 | 3.0 | 5.0 | 3.0 | 5.0 | 3.0 |
| Supply by Diesel | Energy/MWh | - | - | 3,633 | 2,570 | 9,483 | 5,211 | 9,077 | 5,826 |
| Supply by Grid | Energy/MWh | 15,699 | 18,918 | 12,032 | 12,032 | 14,096 | 14,096 | 14,096 | 14,096 |
| Possible Feed-IN | Energy/MWh | 17,251 | 2,130 | - | - | 8,209 | 6,935 | - | - |
| Total Camp Demand | Energy/MWh | 29,849 | 29,849 | 29,849 | 24,598 | 29,849 | 24,598 | 29,849 | 24,598 |

**Table 11: Supply system variant main parameter**

Design of the photovoltaic- and battery- system is equal from the technologies modeled and differ only in their capacity from variant to variant. Differences from variant to variant are described below.

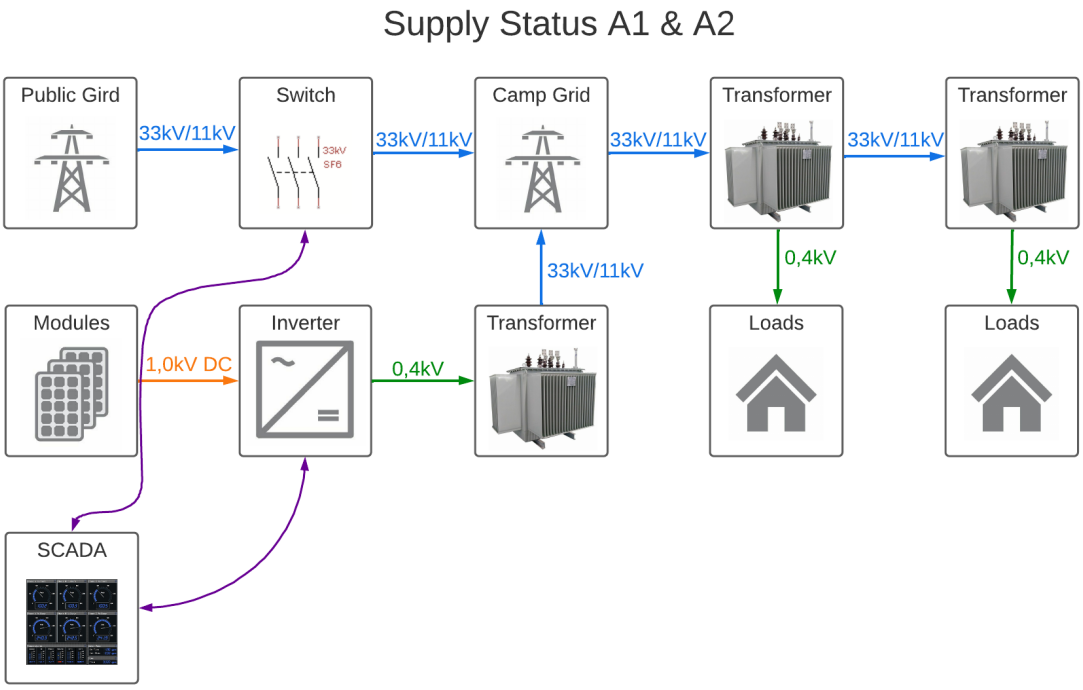


**Figure 21: Block Diagram of supply situation for variants A1 & A2**

#### 4.4.2.1 A1

This supply variant represents the common practice for grid connected PV-Systems in Europe. It does not represent a backup supply system and is only working when the public grid is operating, in case of a public grid outage the camp is without electricity. The used technology are 41,500 standard modules on a fixed tilt mounting structure connected to about 600 x 25kVA PV-inverters. The connection to the camp internal medium voltage gird is through a 15MVA transformer.

Basic attributes of this variant:

- Requires a change in schedule to ensure the grid is always on
- No backup functionality
- Utilizing all land available within the camp to build up the maximum power PV-Plant
- Overcapacity supplied into the grid is more than the grid supplies during the times when no or low solar irradiance is available
- Low technology hurdle / low complexity

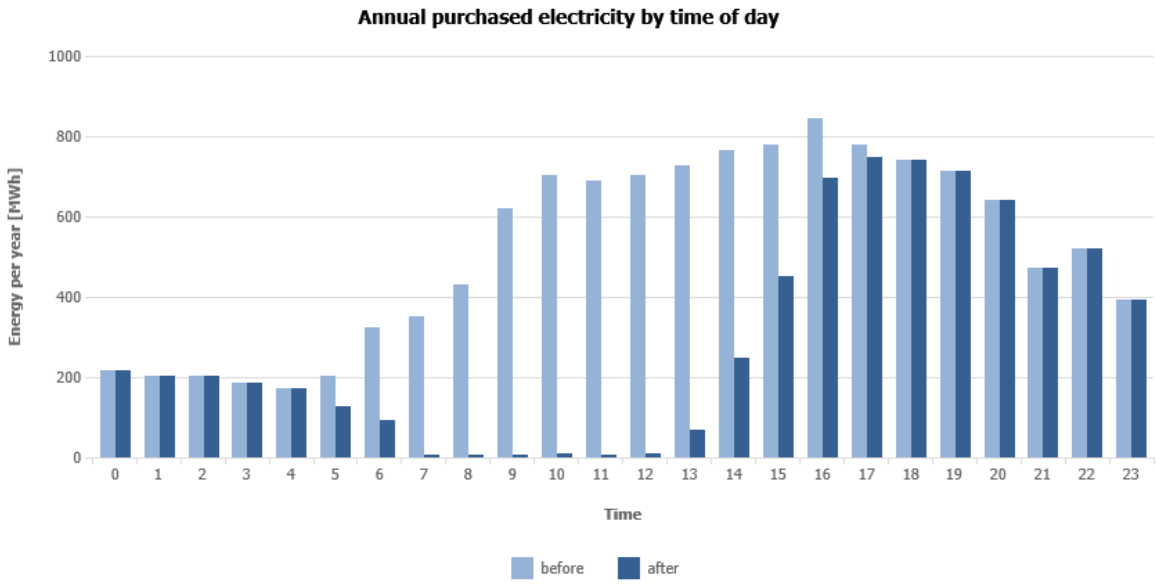


**Figure 22: Winter supply situation before and after PV-System with 16.6MWp**

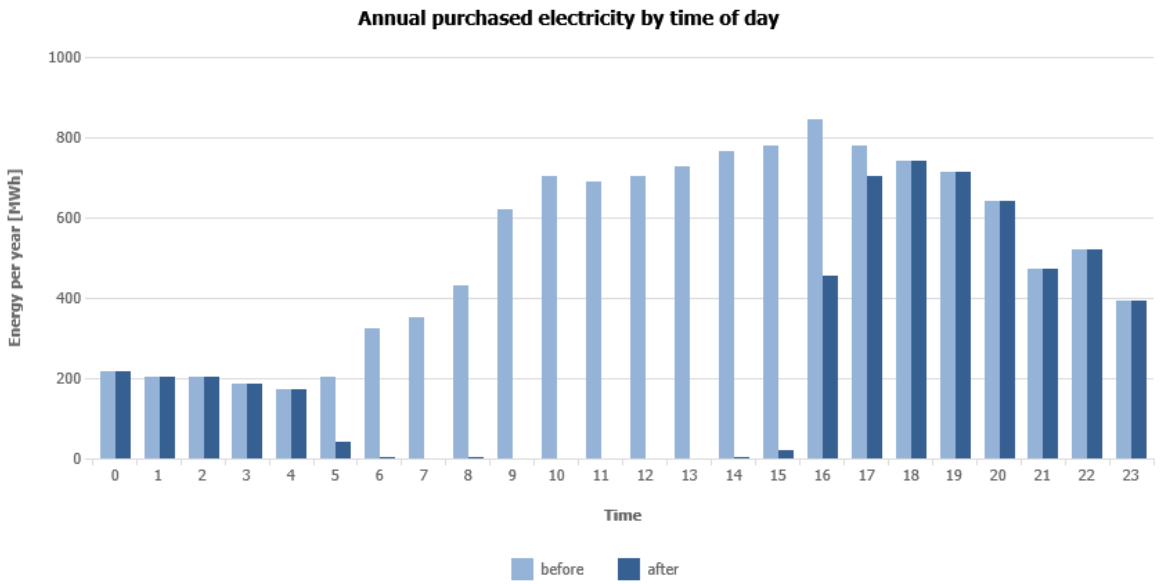


**Figure 23: Summer supply situation before and after PV-System with 16.6MWp**

| | |
|---|---|
| Pro | • low technical complexity, a broad spectrum of commercial solutions available in the market<br>• high solar fraction >45% of the total energy demand<br>• high grid feed-in of more than grid demand<br>• Improved supply for all households with continuous 6A supply<br>• use existing power distribution infrastructure<br>• no need for recycling/waste management of batteries |
| Contra | • no backup functionality, when the grid is off there is no electricity in the camp<br>• reorganization of the medium voltage grid required to separate the supply of Domiz 1 from Domiz 2<br>• significant change in grid schedule required (grid has to provide more energy than before) |

### 4.4.2.2 A2

This supply variant represents the common practice for grid connected PV-Systems in Europe. It does not represent a backup supply system and is only working when the public grid is operating, in case of a public grid outage the camp is without electricity. The used technologies are 17,250 standard modules on a fixed tilt mounting structure connected to about 200 x 25kVA PV-inverters. The connection to the camp internal medium voltage grid is done through a 5 MVA transformer.

The difference to A1 is the size of the PV-Power Plant is designed to optimize self-consumption by the camp with minimal overcapacity.

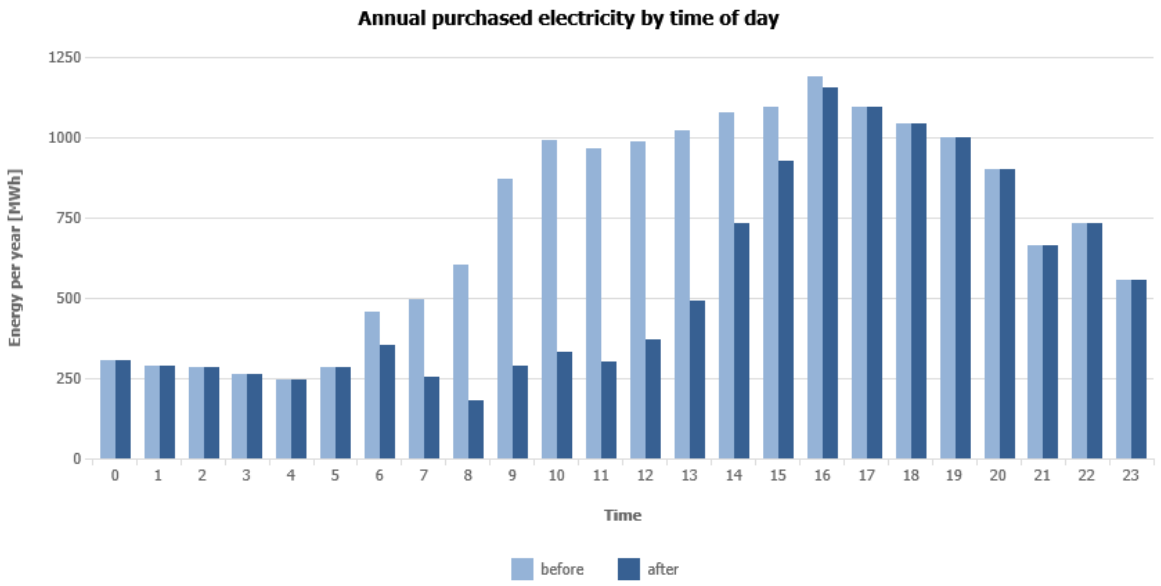


**Figure 24: Winter supply situation before and after PV-System with 6.9MWp**

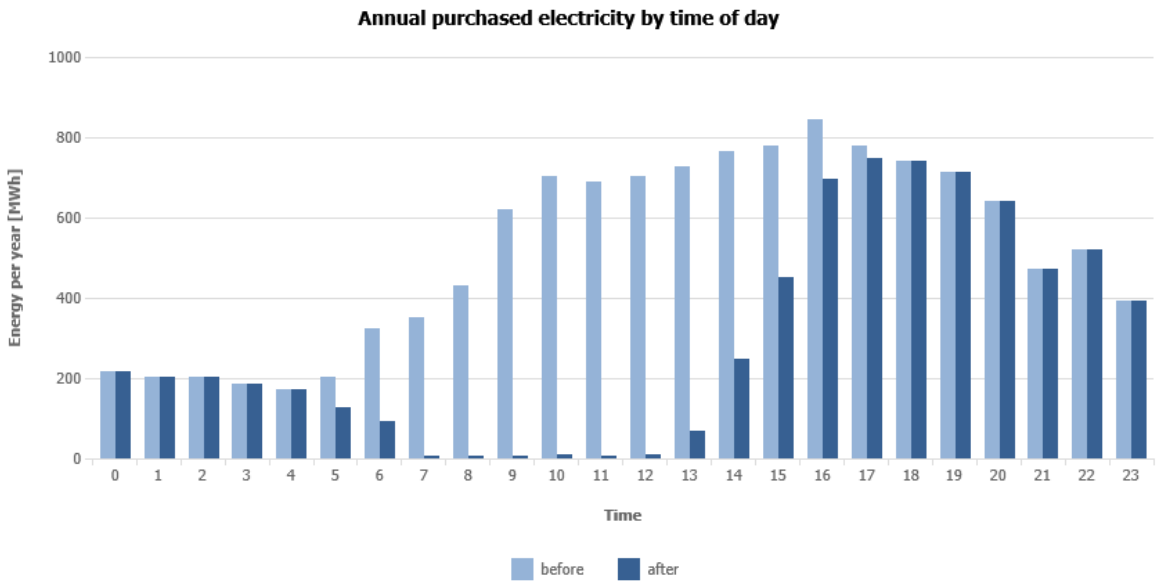


**Figure 25: Summer supply situation before and after PV-System with 6.9MWp**

| | |
|---|---|
| Pro | • low technical complexity, a broad spectrum of commercial solutions available in the market<br>• Improved supply for all households with continuous 6A supply<br>• use existing power distribution infrastructure<br>• no need for recycling/waste management of batteries |
| Contra | • no backup functionality, when the grid is off there is no electricity in the camp |

| | |
|---|---|
| | • reorganization of the medium voltage grid required to separate Domiz 1 from Domiz 2 supply<br>• significant change in grid schedule required (grid has to provide more energy than before) |

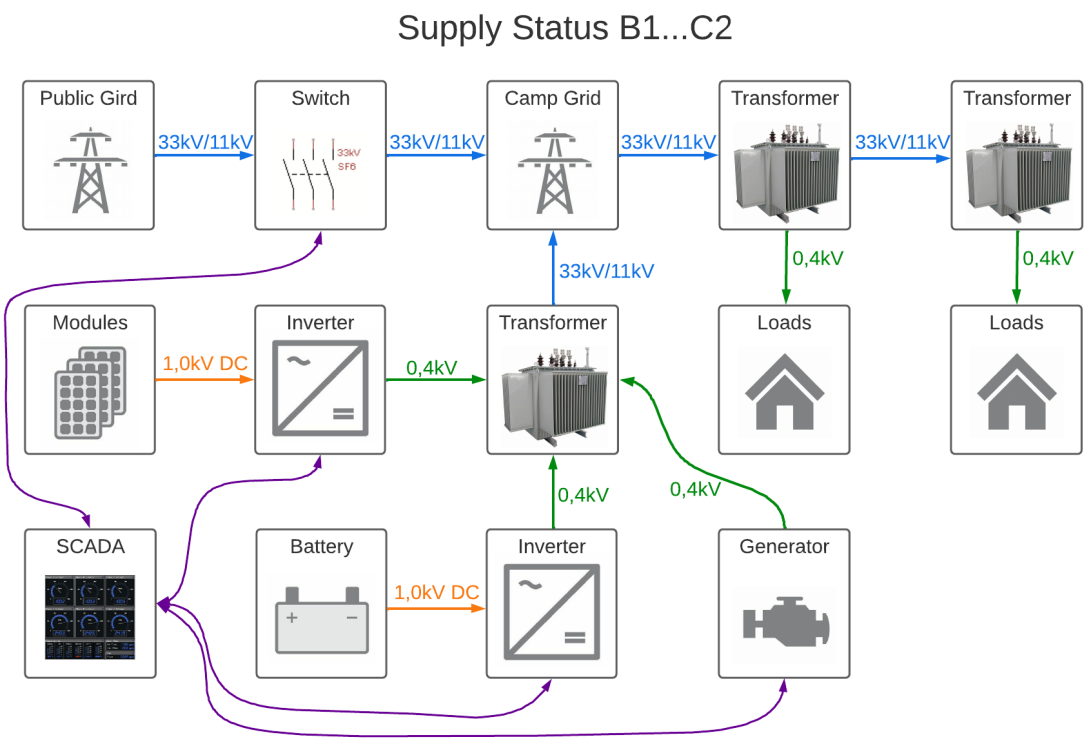


**Figure 26: Block Diagram of supply situation for variants B1…C22**

### 4.4.2.3 B1

This supply variant represents a hybrid system with full backup and black start. The used technology are 28,750 standard modules on a fixed tilt mounting structure connected to about 400 x 25kVA PV-inverters. The connection to the camp internal medium voltage grid is done through a 10MVA transformer. To provide backup functionality a battery system with an AC inverter capacity of 6MVA and a battery capacity of 8.4MWh is connected. To cover the entire energy required during the grid blackout periods diesel generators with 4MVA are required.

Basic attributes of this variant:

- Requires a change in schedule to ensure the grid is on at night (18:00 to 06:00)
- Full backup/black start functionality
- Power-plant designed to cover 80% of the daytime demand over the year, require less land than available within the camp.
- Require diesel backup for winter months and rainy periods to cover daytime supply

To demonstrate the principles of simulation and modeling background, this scenario is suitable as it contains all relevant sources and conversions. The load profile for this scenario shows that the system has to cover the demand during daytime - a weekly profile is shown in Figure 27. Night demand is covered by the public grid and blended out.

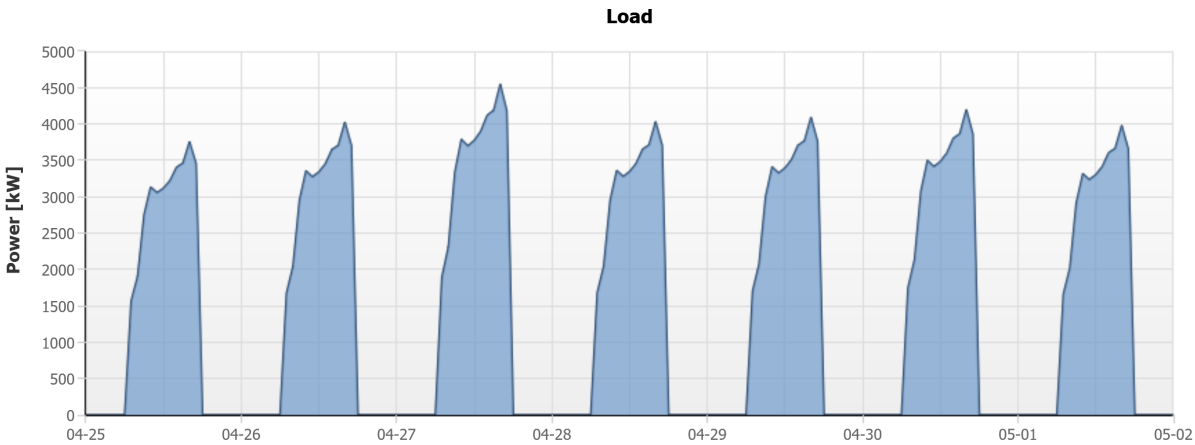


**Figure 27: Weekly Profile of the night schedule (so public grid at night)**

To demonstrate the demand over the entire year Figure 28 below shows the power in different colors over the year on the x-axis and the daytime on the y-axis. The power, represented by the colors in the visualization of the profile, needs to be covered by the supply system.

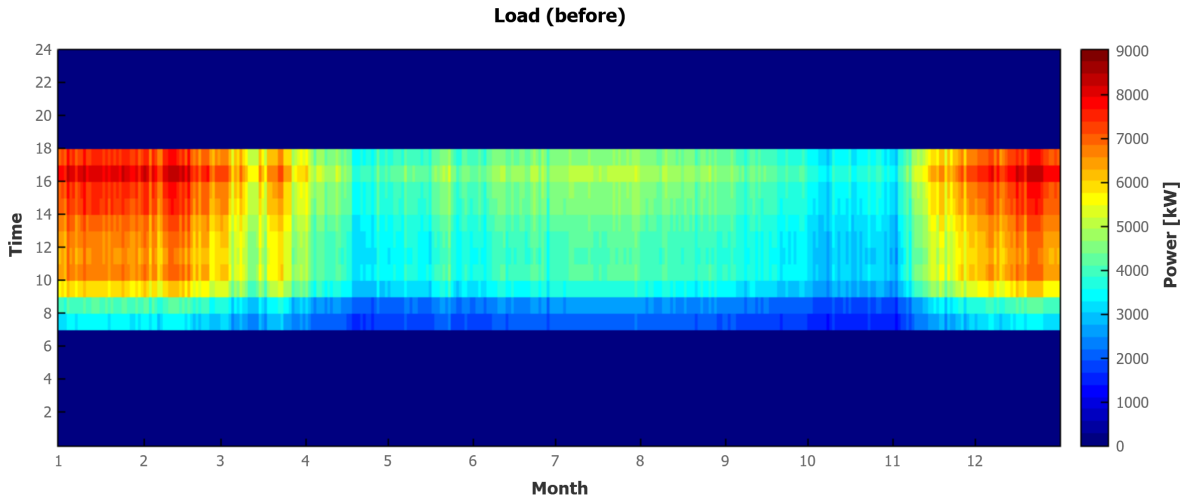


**Figure 28: power over time to be supplied by the new energy system**

Figure 29 shows the power that needs to be provided by the battery system and the backup diesel generator. All the other dark blue areas that disappeared compared to Figure 28 are directly covered by photovoltaic power generation.

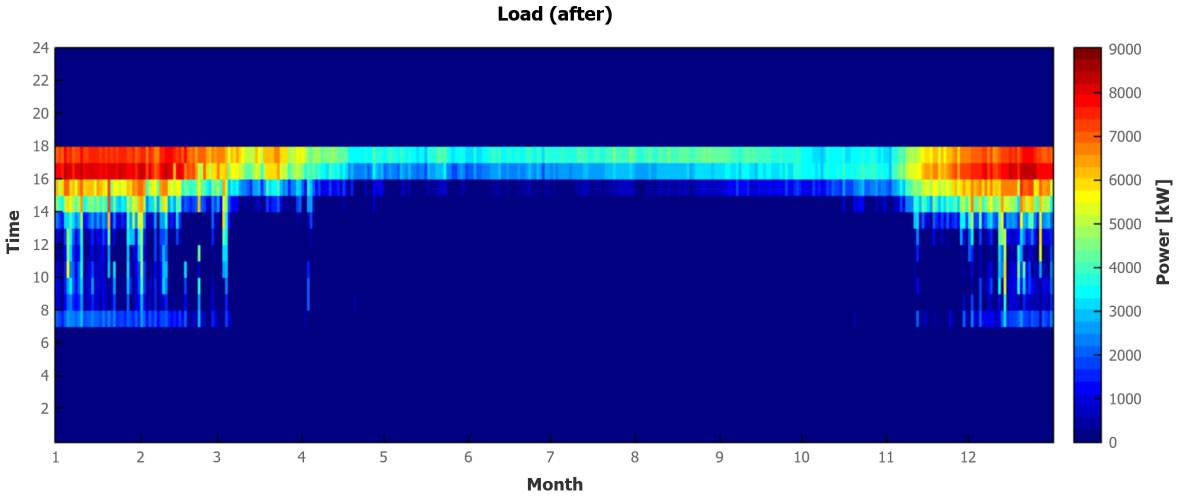


**Figure 29: remaining power profile after photovoltaic supply**

The photovoltaic capacity needs to cover the energy needed to charge the battery while at the same time supplying the demand throughout a given day. So the PV-System is always larger than the average demand from the loads.

In this scenario 63% of the PV-energy is used, 53% is used directly.

84% of the demand is covered by PV-energy and the rest needs to be covered by diesel generators.

| | |
|---|---|
| Pro | • full backup functionality<br>• improved supply for all households with continuous 6A supply<br>• use existing power distribution infrastructure |
| Contra | • medium technical complexity with advanced control system<br>• additional diesel generator required to cover winter demand<br>• reorganization of the medium voltage grid required to separate Domiz 1 from Domiz 2 supply<br>• change in grid schedule required |

### 4.4.2.4 B2

This supply variant represents a hybrid system with full backup and black start capabilities. The used technologies are 17,250 standard modules on a fixed tilt mounting structure connected to about 200 x 25kVA PV-inverters. The connection to the camp internal medium voltage grid is done through a 5 MVA transformer. To provide backup functionality a battery system with an AC inverter capacity of 4MVA and a battery capacity of 5.6MWh is connected. To cover the entire energy required during the grid blackout periods diesel generators with 3MVA are required.

The difference to B1 is the lower demand and the smaller supply system.

- Reduced supply to 4A level per household (annual demand down to 24,598 MWh)

| | |
|---|---|
| Pro | • backup functionality<br>• use existing power distribution infrastructure |
| Contra | • energy limitation for the backup functionality<br>• reduced supply of 4A per shelter during daytime |

| | |
|---|---|
| | • change over or smart metering required<br>• medium technical complexity with advanced control system<br>• additional diesel generator required to cover winter demand<br>• reorganization of the medium voltage grid required to separate the supply to Domiz 1 from Domiz 2<br>• change in grid schedule required |

### 4.4.2.5 C1

This supply variant represents a hybrid system with full backup and black start. The used technologies are 28.750 standard modules on a fixed tilt mounting structure connected to about 400 x 25kVA PV-inverters. The connection to the camp internal medium voltage grid is through a 10MVA transformer. To provide backup functionality a battery system with an AC inverter capacity of 6MVA and a battery capacity of 8.4MWh is connected. To cover the entire energy required during the grid blackout periods diesel generators with 4MVA are required.

The difference to B1 is the changed load profile with same energy demand

- No change in schedule
- increased diesel capacity to cover night outages of the public grid

| | |
|---|---|
| Pro | • full backup functionality<br>• improved supply for all households with continuous 6A supply<br>• use existing power distribution infrastructure<br>• no change in schedule needed from grid operator (no impact on current public grid supply system) |
| Contra | • high technical complexity with advanced control system<br>• additional diesel generator required to cover winter demand<br>• high diesel consumption due to night supply |

### 4.4.2.6 C2

This supply variant represents a hybrid system with full backup and black start capabilities. The used technologies are 17,250 standard modules on a fixed tilt mounting structure connected to about 200 x 25kVA PV-inverters. For the connection to the camp internal medium voltage grid is done through a 5 MVA transformer. To provide backup functionality a battery system with an AC inverter capacity of 4MVA and a battery capacity of 5.6MWh is connected. To cover the entire energy required during the grid blackout periods diesel generators with 3MVA are required.

The only difference to B2 is the changed load profile with the same energy demand.

- No change in schedule
- increased diesel capacity to cover night outages of the public grid

| | |
|---|---|
| Pro | • backup functionality<br>• use existing power distribution infrastructure<br>• no change in schedule needed from grid operator (no impact on current public grid supply system) |

| | |
|---|---|
| Contra | • energy limitation for the backup functionality<br>• reduced supply on 4A per shelter during daytime<br>• change over or smart metering required<br>• high technical complexity with advanced control system<br>• additional diesel generator required to cover winter demand<br>• high diesel consumption due to night supply |

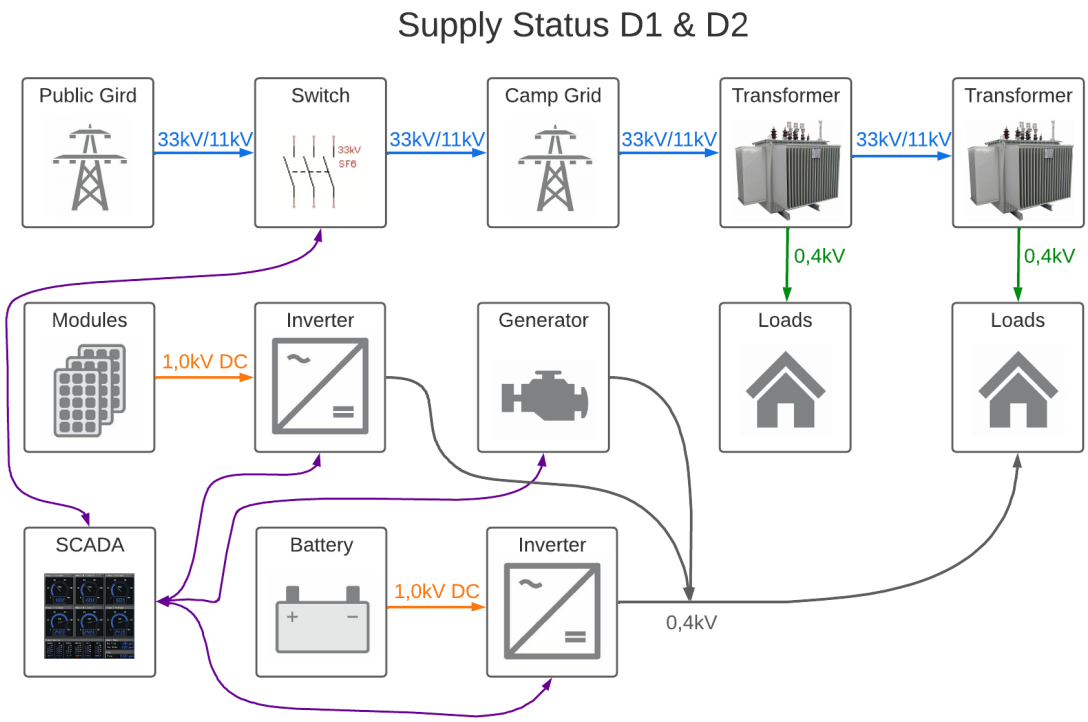


**Figure 30: Block Diagram of supply situation for variants D1 & D2**

### 4.4.2.7 D1

This supply variant represents a hybrid system with full backup and black start. The used technology are 28,750 standard modules on a fixed tilt mounting structure connected to about 400 x 25kVA PV-inverters. There is a separate low voltage grid required to distribute the energy to the households, shops, and infrastructure consumers. To provide backup functionality a battery system with an AC inverter capacity of 6MVA and a battery capacity of 8.4MWh is connected. To cover the entire energy required during the grid blackout periods diesel generators with 4MVA are required.

The difference to C1 is that the power distribution is carried by a separate low voltage grid infrastructure

| | |
|---|---|
| Pro | • full backup functionality<br>• improved supply for all households with continuous 6A supply<br>• no change in schedule needed from grid operator (no impact on current public grid supply system) |
| Contra | • high technical complexity with advanced control system<br>• additional diesel generator required to cover winter demand<br>• high diesel consumption due to night supply<br>• additional low voltage grid infrastructure required |

#### 4.4.2.8 D2

This supply variant represents a hybrid system with full backup and black start capabilities. The used technologies are 17,250 standard modules on a fixed tilt mounting structure connected to about 200 x 25kVA PV-inverters. There is a separate low voltage grid required to distribute the energy to the households, shops, and infrastructure consumers. To provide backup functionality a battery system with an AC inverter capacity of 4MVA and a battery capacity of 5.6MWh is connected. To cover the entire energy required during the grid blackout periods diesel generators with 3MVA are required.

The difference to C2 is that the power distribution is carried by a separate low voltage grid infrastructure

| | |
|---|---|
| Pro | • backup functionality<br>• no change in schedule needed from grid operator (no impact on current public grid supply system) |
| Contra | • energy limitation for the backup functionality<br>• additional low voltage grid infrastructure required<br>• reduced supply on 4A per shelter during daytime<br>• change over or smart metering required<br>• high technical complexity with advanced control system<br>• additional diesel generator required to cover winter demand<br>• high diesel consumption due to night supply |

#### 4.4.3 Grid Conditions

The access to the medium voltage grid is close to the possible PV-Arrays (<50 m) and its capacity is enough to cover supply and feed in.

If the grid in Domiz 1 camp will continue to have two medium voltage feeders the supply systems would need to be divided between the medium voltage feeders, which requires additional transformers and control.

The supply systems would be connected via different medium voltage transformers to the different voltage levels. As the share of the supply capacity between the two feeders is almost 50%, the supply systems would also need to be divided by half.

To keep the Domiz 2 camp on its typical grid schedule the 33 kV-Feeder would need to get a remote operational bypass.

The economical calculations consider the separate feeders with two different medium voltage levels in the camp.

### 4.5 Grid interconnection

Variants A1 to C2 are using the existing power distribution infrastructure. The technical optimal solution is to convert the medium voltage grid in the camp to the 33kV voltage level and have only one feeder from the public substation to the Domiz 1 camp. In all these variantes a communication system for supply control with the Dohuk public substation would need to be established.

For the variants B1 to C2 a grid separation on the medium voltage level needs to be installed to protect the “Island Operation” of the backup system during the times of grid outage.

#### 4.5.1 Assessment of possible electrical Faults and their Impact on the Power Network

The wire and device protection of the transformer stations which carry the energy from the supply system to the grid covers full short circuit and overload protection under IEC Standards for grid protection. Local grid codes can be implemented and are covered in the cost assumptions for the transformer stations.

#### 4.5.2 Impact on the Distribution Grid

The variants (A1, A2, C1, C2) with feed into the grid from the supply system related to PV overproduction are designed with a plant controller for grid stability support for voltage and frequency support.

#### 4.5.3 Grid Control Strategies

The inverters can support the grid in a wide range of control parameters. Voltage support can even be performed at night with the so-called Q@night technology.

The frequency control can be used to reduce feed-in during overproduction which is embedded in each inverter and can be activated on the request of the grid operator.

Besides the automated grid monitoring reactions of the plant controller, the grid operator can manually curtail the system over a secured interface.

#### 4.5.4 Electrical Safety

The current grid is operated as a TT-Grid.

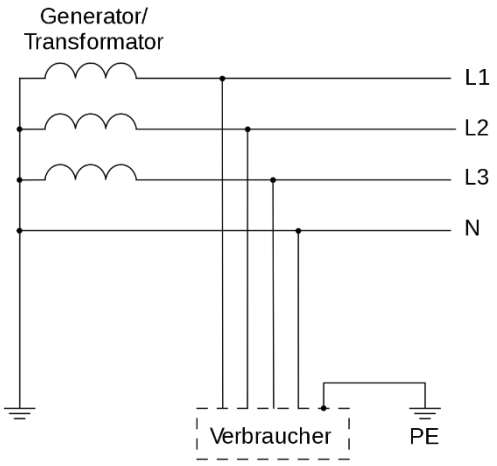


**Figure 31: TT-Grid schematic**

As of the low earthing resistance the ground fault of devices and distribution grid are not allowing the typical protection circuit breakers to trip. It is recommended to use ground fault protection for the individual households to protect from electrical shock.

In the variants A1 to C2 the low voltage safety concept would not be touched as the supply system would be connected to the medium voltage level, away from the end-user.

The variants D1 and D2 would require a low voltage grid to the end user. As mentioned above, it would be preferable to integrate ground fault protection. As this is a new concept and currency unknown to the end-user, additional education on the impact of such an improved safety concept is recommended. The additional cost for the installation of these devices is considered.

## 4.6 Energy Yield Assessment

Representing all PV-Designs used in the energy simulation the data for the power plant variant B1 with 11.5MWp DC power is shown in this chapter.

### 4.6.1 Solar Irradiation Data

Most suitable weather station identified is Abu Kamal in Syria, it is 317km away from Domiz camp, but more relevant from the climate location than closer weather stations in Turkey or Iran.

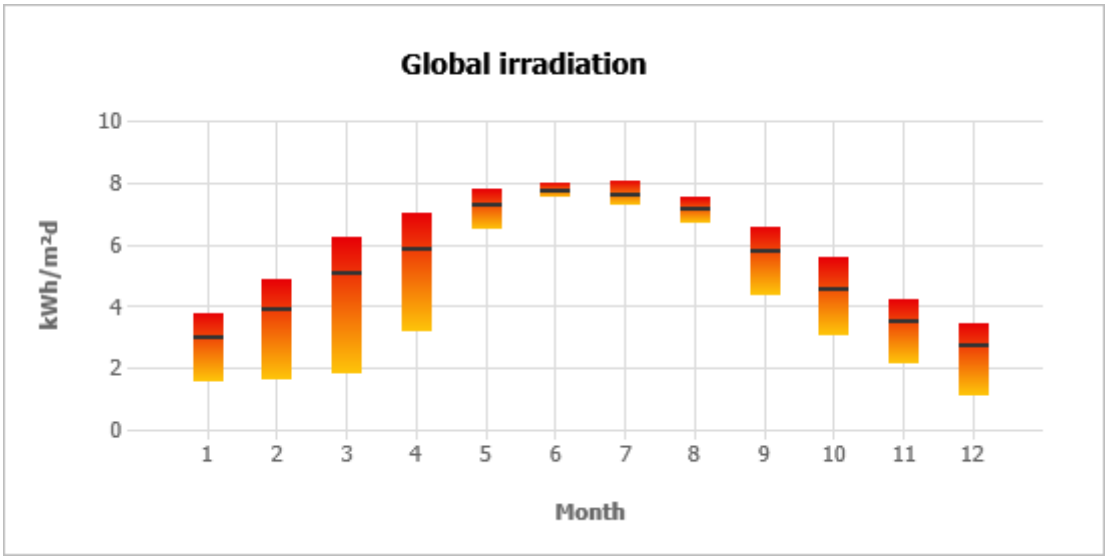


**Figure 32: Global irradiation over one year**

Total annual global irradiation for this station is 1927kWh/m²a

Meteonorm, Nasa-SSE and PVGIS uses the weather stations and extrapolates the actual location coordinates.

| Data Source | Horizontal global irradiation [kWh/m²a] |
|---|---|
| Abu Kamal (Syria) | 1927 |
| Meteonorm | 1666 |
| NASA-SSE | 1773 |
| PVGIS TMY | 1885 |
| **Average** | **1813** |

| | |
|---|---|
| Standard Deviation | 102 |

**Table 12: Horizontal global irradiation**

### 4.6.2 Shading Analysis

The shading analysis in this case is reduced to the row to row shading from the mounting structure. The horizon does not create shading as the area is flat and vegetation is low.

The row to row shading in the chosen design is 2%. The losses can be reduced further by increasing the distance between rows.

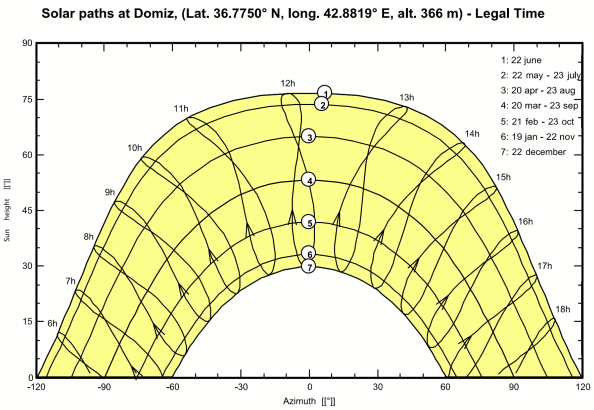


**Figure 33: solar paths at Domiz**

### 4.6.3 Expected Losses

PV System losses are calculated in the DC Model, the AC Model and derived from environnemental conditions.

The inverter design was selected in a way that no clipping losses occur.

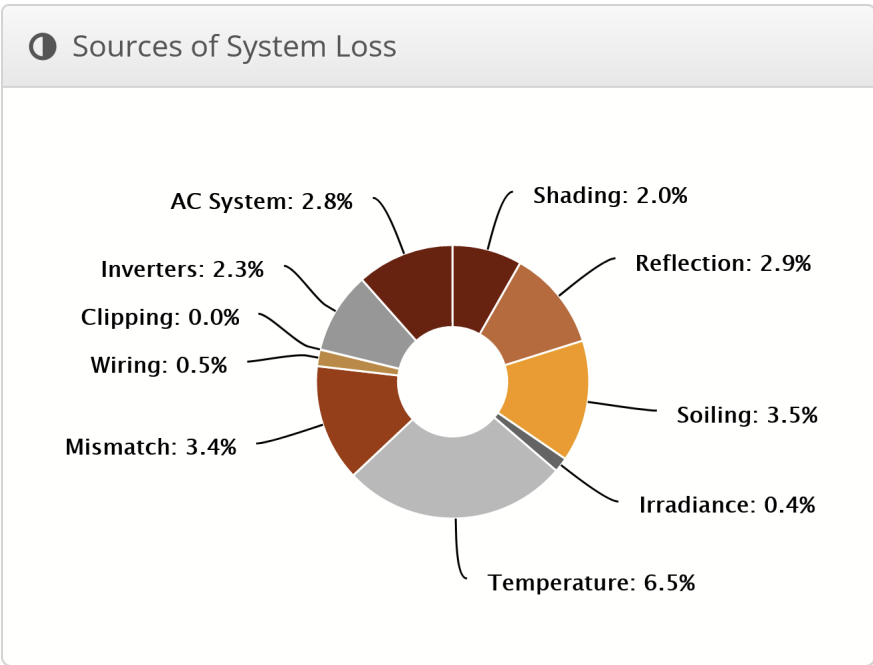


**Figure 34: sources of system loss**

The distribution losses are calculated separately as 5.2% in total, this is including transformer and wiring losses.

### 4.6.4 Energy Yield Simulation for most suitable Technical Design

Main results are summarized in the Table 13. A report on the simulation can be found in the Appendix.

| | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray MWh | E_Grid MWh | PR |
|---|---|---|---|---|---|---|---|---|
| **January** | 65.9 | 28.32 | 6.68 | 96.5 | 94.6 | 1056 | 1033 | 0.929 |
| **February** | 82.6 | 38.03 | 8.54 | 108.3 | 106.3 | 1172 | 1147 | 0.919 |
| **March** | 124.1 | 56.68 | 13.14 | 144.6 | 141.5 | 1513 | 1481 | 0.890 |
| **April** | 152.8 | 78.81 | 17.27 | 162.2 | 158.3 | 1672 | 1639 | 0.877 |
| **May** | 198.1 | 70.22 | 24.07 | 195.3 | 191.0 | 1922 | 1883 | 0.837 |
| **June** | 213.1 | 79.32 | 30.60 | 204.2 | 199.6 | 1959 | 1920 | 0.816 |
| **July** | 214.3 | 80.48 | 34.38 | 208.4 | 203.5 | 1961 | 1922 | 0.801 |
| **August** | 199.0 | 72.39 | 33.27 | 208.3 | 203.8 | 1967 | 1929 | 0.804 |
| **September** | 159.6 | 45.30 | 28.13 | 184.7 | 181.0 | 1777 | 1742 | 0.819 |
| **October** | 113.7 | 44.37 | 22.79 | 146.2 | 143.5 | 1470 | 1441 | 0.855 |
| **November** | 79.6 | 34.14 | 13.86 | 113.6 | 111.4 | 1205 | 1180 | 0.902 |
| **December** | 63.7 | 28.07 | 8.72 | 95.4 | 93.6 | 1037 | 1015 | 0.923 |
| Year | 1666.5 | 656.14 | 20.19 | 1867.8 | 1828.2 | 18710 | 18332 | 0.852 |

| Legends: | | | | |
|---|---|---|---|---|
| | GlobHor | Horizontal global irradiation | GlobEff | Effective Global, corr. for IAM and shadings |
| | DiffHor | Horizontal diffuse irradiation | EArray | Effective energy at the output of the array |
| | T_Amb | T amb. | E_Grid | Energy injected into grid |
| | GlobInc | Global incident in coll. plane | PR | Performance Ratio |

**Table 13: Main results of energy yield simulation**

The energy profile that is created by the simulation was used to calculate the different supply scenarios A1 to C2. The uncertainties accompanying a solar energy yield prediction based on historical extrapolated irradiance and temperature data are relatively inconsequential compared to the energy management and demand side management of such a supply system modeled for this study. The PV-System needs to be considerably oversized to cover a majority of the demand. The real oversupply of this system can be fed into the public grid when it is available, when it is not available the energy is lost. The range for these losses is wide.

# 5 Economic Feasibility Study

### 5.1.1 Household budget

The households surveyed reported a range of monthly incomes that varied depending upon the employment situation of household members and financial support provided through personal connections and institutional support. Livelihood typologies and their vulnerability are depicted in Figure 35 while the spread of household incomes is shown below in Figure 36.

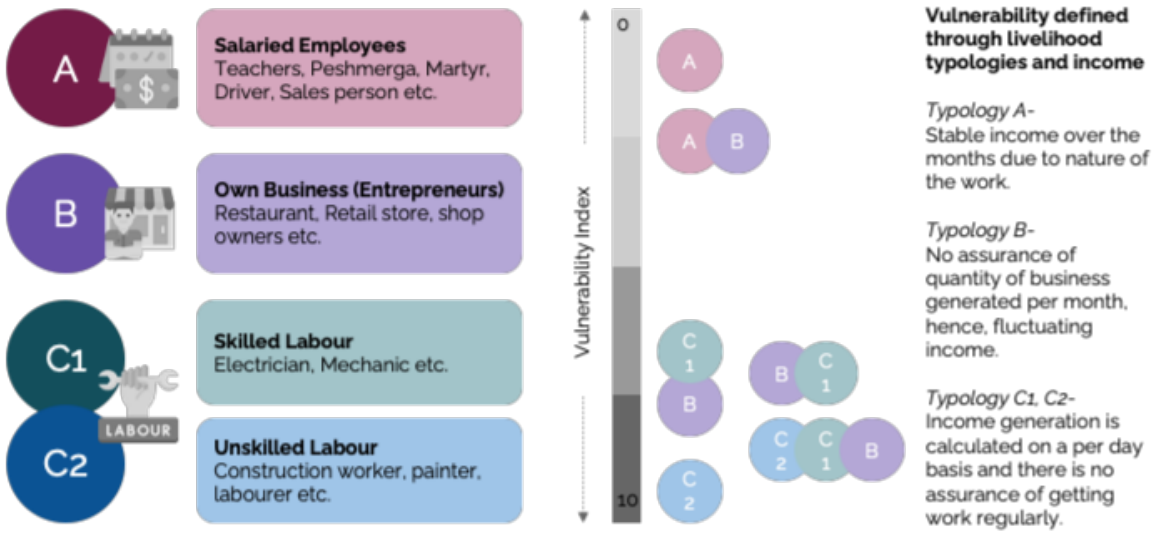


**Figure 35: Livelihood Typologies - Domiz Refugee Camp**

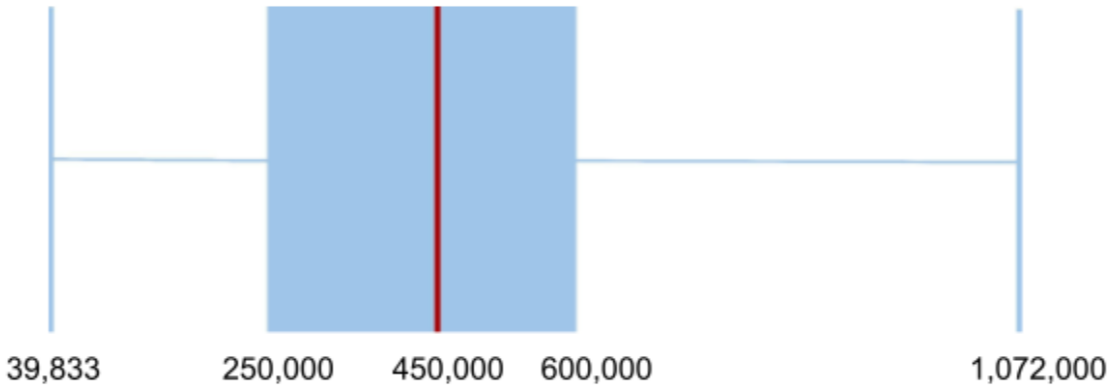


**Figure 36: Average monthly income per month in IQD of surveyed households (outliers excluded)**

Similarly to income the households surveyed reported a range of monthly expenses as depicted in Figure 37 below. The average household had calculated costs of IQD 472,591 per month with the breakdown of expenses as shown in Table 14.

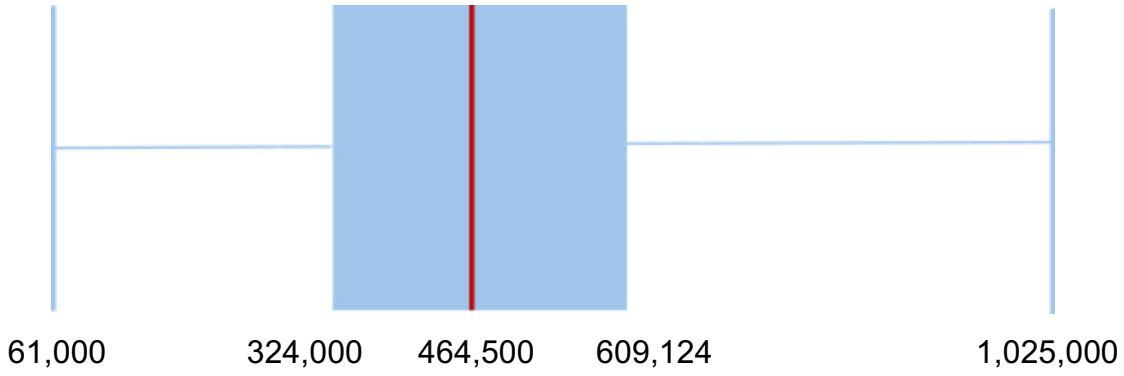


**Figure 37: Average monthly expenses per month in IQD of surveyed households (outliers excluded)**

| Item | Average Cost (IQD) | Percentage of Expenses |
|---|---|---|
| Food | 245,266 | 52% |
| Health | 89,841 | 19% |
| Transport | 34,523 | 7% |
| Internet/wifi | 15,176 | 3% |
| Household Appliances | 8,565 | 2% |
| Clothes | 17,013 | 4% |
| LPG | 11,299 | 2% |
| Diesel Generator | 50,818 | 11% |
| **Total** | **472,591** | |

**Table 14: average costs of different items per household**

The impact of the COVID pandemic was widespread with many families reporting they have been affected by higher prices and a fall in employment opportunities. This was particularly so during the period of the pandemic when strict lockdowns were imposed with households relying upon income from daily construction work particularly affected. This echoes the wider macro

economic trends that have affected the country since the start of the pandemic namely the devaluation of the Iraqi Dinar in December 2020 from approximately USD 1 = IQD 1,191 (2020) to USD 1 = IQD 1,460 (2021). Households have been further affected by a global rise in fuel prices that has seen the cost of diesel and LPG increase significantly, further squeezing household budgets. Given global events these trends are unlikely to reverse in the short to medium term.

### 5.1.2 Economics of electricity

During the survey the price per ampere from the community diesel generator was around IQD 17,500 with the average family spending IQD 52,500 (USD 36) for a 3-ampere connection per month. The price has increased since the previous feasibility study carried out in September 2019 which recorded that each household paid IQD 26,330 (USD 21) per month for electricity from the diesel generator. This rise in price can be attributed to the increase in diesel prices, the devaluation of the Iraqi Dinar as well as the normal fluctuation in the monthly cost of the electricity.

During the period of the study the public grid operated at approximately 12h per day and with energy demand at its highest in winter the price of USD 36 can be taken as being at the higher end of energy prices. The USD 21 price in September 2019 is considered to be at the other end of the spectrum as it was at a time when demand is at its lowest as temperatures are neither too hot nor cold for the continual use of electrical coolers/heaters.

Currently an estimated 2.5% of households qualify for free electricity from the community diesel generator based upon low income or unemployment with eligibility means-tested by camp management.

### 5.1.3 Willingness to pay for a stable electricity supply

The attitude towards the installation of PV in the camp was largely positive with 85% households supporting their installation on household roofs. The support was primarily conditional on the energy provided being cheaper and improving the supply of electricity. Of those who opposed the installation some were worried about panels being installed on their roofs due to safety concerns including fears that the roof would be unable to support it while others worried that they wouldn't be able to afford the maintenance of the system. Anecdotally, households reported during the survey that they were already considering purchasing their own PV systems to provide a more stable source of electricity for their households.

### 5.1.4 Proposed Payment Model

The feasibility study examined possible payment models and prices that would accompany the development of a PV-system. The payment was required to be high enough to cover the O&M of the system as well as the repayment of equity to any private investor. To gain public and institutional support for the project it was also necessary that the fee should be less than that currently paid by households while improving electricity supply. The range of fees that fell into this category and were explored in the different scenarios was between USD 15-25 per month.

The payment model aimed to take into account the economic situation of households, the current payment structure for electricity as well as residents willingness to transition to a new model. We examined two models i) a flat-fee and ii) a consumption-fee before settling on a iii) combined approach that leaves the possibility to transition to a more dynamic pricing model in the future. An important tool to promote energy efficiency within the camp.

- *Flat Fee*

This would most closely replicate the current model of electricity payments used from the diesel generator whereby all households pay a flat fee based upon the size of their connection rather than the amount of electricity their individual household consumes. This model would mean there is no need to install smart meters in the households, reducing the initial infrastructure costs. As the electricity produced from the PV-plant would not be subject to price variations – either based on energy consumed or from external changes in the price of fuel – this model would have an advantage over the current system by allowing operators to charge a consistent monthly fee. Households would therefore have stability in the price of electricity and not see the current fluctuations they do. However, the model would provide no incentive for households to adapt their energy use to either make efficiency savings or adjust their usage to times when energy from the PV is at a maximum.

- *Consumption Fee*

A consumption fee model, whereby households are charged a fee based upon their electricity consumption, would be the most effective way to encourage energy efficiency (see section 4.1.5). Households would have an incentive to turn off devices when not using them and also to switch to more energy efficient devices. Implementing such a model faces a number of challenges both for households and operators. Currently households receive electricity from the public grid for free so may resent having to pay for all electricity consumed. As the monthly bill will depend upon each household's electricity usage it will likely fluctuate although this could be mitigated as the price of energy will remain consistent unlike the fluctuation in diesel prices.

- *Combined Fee*

Our proposal is the implementation of a combined model for fees whereby households pay a standard fee for electricity with an additional fee for households who consume a high-level of electricity. Both payments will be less than the current rate paid for electricity from the diesel generator. This model has the advantage that households will know in advance the maximum amount they'll pay for electricity while also incentivizing energy savings. Ways to easily show households how much energy they are using - possibly through an app - could help to encourage energy efficiency. The model also provides the possibility to move towards a more sophisticated fee based upon electricity used by households.

## 5.2 Economic Calculation

### 5.2.1 Financial Model - Methodology

*Financial model adapted to local conditions. How does the effect of the assumed factors and scenarios have to be computed to deliver comparable economic results that can be used for investment decisions?*

The financial model demonstrates the economic viability of the technical proposals outlined in section 4.4.2. By illustrating a business case for each model it allows a decision to be made on the final configuration of the project and to initiate negotiations with financial backers.

Most of the input parameters will be uncertain until the PV power plant is operational; consequently the decision to build and finance the plant will have to be taken with some risk. A sensitivity analysis has therefore been carried out to ascertain the level of this risk.

All eight technical scenarios will be calculated within the financial model, to see which ones are economically feasible.

| | | Public Grid Parallel | | | | | | Seperate Grid Infrastructure | |
|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical schedule | |
| Source | Unit | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| PV-System Capacity | Power/MW | 16.6 | 6.9 | 11.5 | 6.9 | 11.5 | 7 | 11.5 | 6.9 |
| Battery-System Capacity | Power/MW | - | - | 6.0 | 4.0 | 6.0 | 5 | 6.0 | 4.0 |
| | Energy/MWh | - | - | 8.4 | 5.6 | 8.4 | 5 | 8.4 | 5.6 |
| Supply by PV/ESS | Energy/MWh | 14,035 | 10,816 | 14,184 | 9,996 | 6,270 | 5,291 | 6,676 | 4,676 |
| Diesel Power | Power/MW | | | 4.0 | 3.0 | 5 | 3 | 5 | 3 |
| Supply by Diesel | Energy/MWh | - | - | 3,633 | 2,570 | 9,483 | 5,211 | 9,077 | 5,826 |
| Diesel consumption | Liter | - | - | 1,133,496 | 801,840 | 2,958,639 | 1,625,794 | 2,832,074 | 1,817,781 |
| Supply by Grid | Energy/MWh | 15,699 | 18,918 | 12,032 | 12,032 | 14,096 | 14,096 | 14,096 | 14,096 |
| Possible Feed-IN | Energy/MWh | **17,251** | 2,130 | - | - | 8,209 | 6,935 | - | - |
| Load | Energy/MWh | 29,849 | 29,849 | 29,849 | 24,598 | 29,849 | 24,598 | 29,849 | 24,598 |

**Table 15: different power sources compared in the eight scenarios**

Input Parameters

Main input parameters for the financial models are:

- Estimated annual electricity yield given in MWh per year of each electricity source
- Estimated annual load
- Investment costs or capital expenditure (CAPEX)
- Annual operating expenses (OPEX)
- Monthly fee for the electricity supply
- Economic assumptions in general, and
- Financing parameters.

The Model

The financial model calculates the yearly cash flow of the power plant based upon the specified input parameters. The main input criteria equity/grant ratio and monthly fee for the electricity supply are optimized to give a positive annual cash flow: a lower monthly fee has been given priority over a higher share of equity. The payback period for the equity and the Return on Equity (IRR) are fixed at 10 years and 6%.

Output Parameters

As a result, the financial model calculates:

- **Net Present Value (NPV)** of the project, a measure for the discounted cash flow. The NPV is a profit based criteria which takes into account the profit of all future years discounted to present with a set discount factor. The discount factor shall be in line with the risk of the project. A low risk project shall have a lower discount factor than a high risked project. The NPV does not take into account the project grant which is necessary for all scenarios - except A2b - to be financially viable.
- **Equity/Grant ratio**, to receive the predefined payback period and IRR.

- **Levelized Cost of Energy (LCOE**), is one of the primary metrics for determining the cost of electricity produced by a power plant. It is calculated by accounting for all of a system's discounted expected lifetime costs which are then divided by the system's discounted lifetime expected power output (kWh).

### 5.2.2 Cost Summary of Technologies

The technology costs are estimated based on the current market prices plus ca. 10% extra for unpredictable developments. In reality costs are expected to be significantly lower than those calculated in the model.

The costs for the PV system including the engineering, procurement and construction (EPC) are assumed to be 820$/kWp. The costs include the special requirements on the mounting system because of the environmental conditions, outlined in section 4.3. It also considers that the installation of the system will include a training of the workers to increase the technical knowledge of PV in the region.

The battery system costs are estimated to be 570$/kWp with a required replacement of the batteries after 12 years for 200$/kWp. The replacement costs are lower than the initial costs because only the battery racks require replacing and not the total battery system with inverters and enclosure. Furthermore a cost reduction is expected within the market over the coming years.

The costs for the grid infrastructure is expected to be 30$/kWp installed PV capacity. For scenarios D1+D2 extra costs of USD 350,000 occur for the installation of a separate grid infrastructure.

In scenarios B1-D2 it should be the aim to include the current diesel generator operator into the business case and to integrate the existing system to cover the share of required diesel electricity. However, as it is unknown if the business case is of interest for the diesel operator, the financial models consider the purchase and operation of a new generator.

The European market standard for operation and maintenance costs of PV plants is 1.3% - 1.4% of the PV/ESS system investment costs, this also covers the costs for the spare parts. Considering the higher cleaning efforts required owing to the dusty environment and the rather inexperienced workers on site, the financial models calculate O&M costs at 1.6% of the PV/ESS system costs. For the operation and maintenance of the diesel generator an additional 4% of the diesel generator investment costs are estimated.

For the uninterrupted electricity supply and the after sales service an O&M fee of 34.20 $/connection will be charged. As this fee is independent of the technology scenario and not part of the specific energy cost, it is not part of the overview.

| | | Public Grid Parallel | | | | | | Seperate Grid Infrastructure | |
|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical schedule | |
| Source | Unit | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| **Investment** | | $ 15,910,000 | $ 7,665,000 | $ 16,915,941 | $ 11,271,706 | $ 17,054,176 | $ 10,844,706 | $ 17,404,176 | $ 11,621,706 |
| Grid Infrastructure | $ 30.00 | $ 498,000 | $ 207,000 | $ 345,000 | $ 207,000 | $ 345,000 | $ 204,000 | $ 695,000 | $ 557,000 |
| PV-System | $ 820.00 | $ 13,612,000 | $ 5,658,000 | $ 9,430,000 | $ 5,658,000 | $ 9,430,000 | $ 5,576,000 | $ 9,430,000 | $ 5,658,000 |
| Battery System | $ 570.00 | $ - | $ - | $ 4,788,000 | $ 3,192,000 | $ 4,788,000 | $ 2,850,000 | $ 4,788,000 | $ 3,192,000 |
| Smart Meetering | $ 300.00 | $ 1,800,000 | $ 1,800,000 | $ 1,800,000 | $ 1,800,000 | $ 1,800,000 | $ 1,800,000 | $ 1,800,000 | $ 1,800,000 |
| Battery Replacment after 12 Years | $ 200.00 | $ - | $ - | $ 1,680,000 | $ 1,120,000 | $ 1,680,000 | $ 1,000,000 | $ 1,680,000 | $ 1,120,000 |
| Diesel Generator Invest/kW | $ 138.24 | $ - | $ - | $ 552,941 | $ 414,706 | $ 691,176 | $ 414,706 | $ 691,176 | $ 414,706 |
| Diesel Fuel cost | $ 0.60 | | | $ 680,097.60 | $ 481,104.00 | $ 1,775,183.46 | $ 975,476.44 | $ 1,699,244 | $ 1,090,669 |
| Maintainance Cost PV/ESS | 1.6% | $ 217,792 | $ 90,528 | $ 227,488 | $ 141,600 | $ 227,488 | $ 134,816 | $ 227,488.00 | $ 141,600 |
| Maintainance Cost Diesel Gen | 4.0% | $ - | $ - | $ 22,117.65 | $ 16,588.24 | $ 27,647 | $ 16,588 | $ 27,647 | $ 16,588 |
| **Energy Cost Diesel per kWh** | | | | $ 0.201 | $ 0.202 | $ 0.194 | $ 0.194 | $ 0.194 | $ 0.194 |
| **Energy cost PV/ESS per kWh** | 20 | $ 0.072 | $ 0.044 | $ 0.076 | $ 0.071 | $ 0.172 | $ 0.128 | $ 0.164 | $ 0.155 |
| **Energy cost total** | per Year | $ 1,013,292 | $ 473,778 | $ 1,803,147 | $ 1,223,613 | $ 2,917,586 | $ 1,689,851 | $ 2,859,147 | $ 1,850,677 |
| **System LCOE** | per kWh | $ 0.072 | $ 0.044 | $ 0.101 | $ 0.097 | $ 0.185 | $ 0.161 | $ 0.182 | $ 0.176 |

**Table 16: technology costs**

### 5.2.3 Summary Initial Project Costs

The subsequent project development will be carried out by the current project coordinators from atmosfair gGmbH and the American University of Kurdistan in partnership with UNHCR. This will involve coordination with national and international stakeholders to finalize the proposed PV-system, the raising of funds to cover the initial infrastructure costs. the development of the community fund, and the supervision and reporting of the installation and operation of the system. These costs will total USD 100,000 covering a period of 12-18 months.

Following the successful installation of the PV-system the project management team will operate a reduced role to ensure its smooth operation for a period of five years. This will include monitoring and reporting on the project's performance, supporting the on-site management team, liaising with the international consortium members and disseminating knowledge for the development of future projects. The cost of this phase will be USD 25,000 per year totalling USD 125,000 for five years.

### 5.2.4 Base Case Assumptions

For the calculation of the financial decision parameters, the financial assumptions play an important role. Large scale PV power plants are relatively new in the KRI, a region that has relatively little experience with such large scale projects and where banks have not yet acquired the needed field expertise. For these reasons, we recommend taking a conservative but realistic approach in respect to the financial assumptions. All financial assumptions are based on the field study, publicly available data or, wherever not available, on assumptions drawn from analogies. All income calculations or indexations from above are taken into account in the financial model.

Plant Assumptions

Eight different technology scenarios are assumed including various combinations of a PV plant with crystalline module technology on a fixed mounted structure, a lithium battery storage, a common diesel generator and the national grid. The system sizes and annual yield varies within the scenarios:

| | | Public Grid Parallel | | | | | | Seperate Grid Infrastructure | |
|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical schedule | |
| Source | Unit | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| PV-System Capacity | Power/MW | 16.6 | 6.9 | 11.5 | 6.9 | 11.5 | 7 | 11.5 | 6.9 |
| Battery-System Capacity | Power/MW | - | - | 6.0 | 4.0 | 6.0 | 5 | 6.0 | 4.0 |
| | Energy/MWh | - | - | 8.4 | 5.6 | 8.4 | 5 | 8.4 | 5.6 |
| Supply by PV/ESS | Energy/MWh | 14,035 | 10,816 | 14,184 | 9,996 | 6,270 | 5,291 | 6,676 | 4,676 |
| Diesel Power | Power/MW | | | 4.0 | 3.0 | 5 | 3 | 5 | 3 |
| Supply by Diesel | Energy/MWh | - | - | 3,633 | 2,570 | 9,483 | 5,211 | 9,077 | 5,826 |
| Diesel consumption | Liter | - | - | 1,133,496 | 801,840 | 2,958,639 | 1,625,794 | 2,832,074 | 1,817,781 |
| Supply by Grid | Energy/MWh | 15,699 | 18,918 | 12,032 | 12,032 | 14,096 | 14,096 | 14,096 | 14,096 |
| Possible Feed-IN | Energy/MWh | **17,251** | 2,130 | - | - | 8,209 | 6,935 | - | - |
| Load | Energy/MWh | 29,849 | 29,849 | 29,849 | 24,598 | 29,849 | 24,598 | 29,849 | 24,598 |

**Table 17: different power sources compared in the eight scenarios**

The start of operations is considered to be the date of grid connection. It is therefore assumed that the plant will be connected in January 2023. Even though solar power plants have a life expectancy of over 30 years, in the financial model an operation time of 20 years is assumed with a renewal of the batteries after 12 years.

Revenue Assumptions

As an electricity tariff per kWh is not common in the region, the electricity pricing will be based on a basic fee per connection plus an extra fee for consumers with a high electricity usage (see section 5.1.4). The consumers pay a standard fee for electricity of between USD 15 - 25 per month depending on the scenario. The payments are less than the current rate paid for electricity from the diesel generator across the year. Based upon current estimates of low income households receiving free electricity from the diesel generator it is assumed that 2.5% of all consumers will not be able to pay any fee. Those households will get an exception of payment following the current needs assessment by camp management. It is assumed that all consumers are paying the same basic fee independently if they are a household, a shop or a daily operation facility. In a more detailed business case the consumer groups should be considered individually which should increase revenue. Customers who consume a high-level of electricity will pay an additional fee of 5 USD/month. It is assumed that 10% of all customers will pay such an additional fee. This fee will be used to directly finance the community fund.

The financial analysis is based on USD. For the analysis, the exchange rate is set to 1 USD for 1445 IQD. The effective fee in IQD will be assessed on a variety of price indices to compensate for inflation and exchange rate changes. This model is assuming a fixed exchange rate of 1445 IQD / 1 USD and does not assume any fee increases.

Financial Assumptions

A linear depreciation over the operation period of 20 years is applied to investment cost or capital expenditure (CAPEX) and financing costs. No Corporate Income Tax is applied as all scenarios wouldn't be economical without the grant.

Cost Assumptions

The CAPEX includes the following: EPC remuneration, further investments for infrastructure, project development costs, consultants and interest during construction. The overall estimated CAPEX varies in the eight scenarios.

The annual cost or operating expenditure (OPEX) includes the following: remote monitoring, operations & maintenance, replacement cost, insurance, security and administration. The overall estimated OPEX amounts to 1.6% of the PV / ESS system costs, as well as 4% of the

diesel generator costs per year. For the battery replacement after 12 years additional costs of 200$/kWp are considered.

For the uninterrupted electricity supply and the after sales service a O&M fee of 34.20 $/connection will be charged independent of the selected technology scenario.

The fuel costs for the Diesel generator are calculated with 0.60 USD/liter.

The annual inflation rate for Iraq is assumed to be 5.3% and for the USD 7.9% based on the current inflation rate. The O&M costs will increase by 2% every 5 year

Project Finance Assumptions

The equity ratio varies in the financial models, but the aim was to have it as high as economically possible. The payback period of the equity is always 10 years and the IRR 6% with a yearly repayment, The financing structure of the project can be compared to international project financing standards for similar projects.

Debt was not considered. The rest of the financing is assumed to be a non-refundable grant provided by international donors.

### 5.2.5 Option: Carbon Credits

It is an option to register the project as a climate protection project under the Gold Standard and to develop it accordingly. This provides an additional project income through the sales of the Gold Standard certificates which can be generated per verified tonne CO2 emission reduction. At least three Sustainable Development Goals (SDGs) need to be positively impacted through the project activity. The following positive impacts are possible:

SDG 7: Affordable and clean energy: Through the project, the amount of people with access to affordable, reliable and modern energy services increase by introducing clean renewable energy technology. The availability of electricity will be improved through clean PV energy. (Contribution to Target 7.1 “By 2030, ensure universal access to affordable, reliable and modern energy services”)

SDG 8: Decent work and economic growth: In the frame of the project, there will be employment opportunities for local people in activities related to installation, operation and maintenance of the plant. No discrimination based on gender, age, religion, sexual orientation or any other bias will be tolerated. Women and men will be paid equally for equal value. (Contribution to Target 8.5 “By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value” )

SDG 13: Climate action: Reduction of GHG emissions from baseline electricity sources like diesel generators and replacing those with climate-friendly solar technology which benefits local households and community facilities in Domiz 1. The camp is connected to a national grid with many shortages and relies therefore on diesel generators that emit greenhouse gases. As the project activity aims to reduce the use of diesel generators by climate friendly PV, the project activity will reduce 1 tonne of CO2 emissions per avoided MWh generated by a diesel generator. The amount of reduced CO2 emissions per year depends on the selected

technology scenario and at the chosen methodology at the time of project registration. It can be estimated that an average price of USD 20 can be achieved per verified tonnes of CO2 emission reduction. (Contribution to Target 13.2 “Integrate climate change measures into national policies, strategies and planning” and 13.B “Promote mechanisms for raising capacity for effective climate change-related planning)

atmosfair will be able to register the project activity under the Gold Standard mechanism, as well as perform the annual verification together with external auditors. Costs for the registration and required renewal are USD 50,000 every five years (calculated as USD 10,000 per year). The annual costs for the verification process are EUR 30,000.

| | | Public Grid Parallel | | | | | | Seperate Grid Infrastructure | |
|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical schedule | |
| Source | Unit | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| Diesel savings | MWh/a | 10,501.88 | 10,502 | 6,869 | 7,931.88 | 1,019.06 | 5,291.00 | 1,424.72 | 4,675.66 |
| CO2 savings | t/a | 10,501.88 | 10,502 | 6,869 | 7,932 | 1,019 | 5,291 | 1,425 | 4,676 |
| Potential income through sales of certificates | USD/a | 210,038 | 210,038 | 137,378 | 158,638 | 20,381 | 105,820 | 28,494 | 93,513 |
| Costs for annual verification | USD/a | -30,000 | -30,000 | -30,000 | -30,000 | -30,000 | -30,000 | -30,000 | -30,000 |
| Costs for project registration and renewal every 5 year | USD/a | -10,000 | -10,000 | -10,000 | -10,000 | -10,000 | -10,000 | -10,000 | -10,000 |
| | | | | | | | | | |
| Additional annual project revenue through carbor | USD/a | 170,038 | 170,038 | 97,378 | 118,638 | 10,619 | 65,820 | - 11,506 | 53,513 |

**Table 18: costs and annual revenue from the project**

Within the scenario C1 and D1 a registration of the project as a climate protection project is not feasible, as the diesel savings are too low meaning the potential income through the sale of the certificates is lower than the costs for the registration and annual verification.

In general it needs to be acknowledged that there is a high degree of uncertainty about the price development on the voluntary carbon market.

### 5.2.6 Summary and Base Case Results

All eight technical scenarios were simulated in a financial model. In all financial models the following parameter were fixed:

- payback period equity 10 years
- IRR equity 6%
- Corporate income tax 0%
- O&M costs increase every 5 years 2%
- Diesel fuel costs 0,60 USD/liter
- O&M costs year: 1.6% of PV/ESS CAPEX + 4% of Diesel Capex + 34.2 USD/connection
- fee for high electricity use 5 USD/month, to be paid by 10% of all consumers
- payment failures 2.5% of all consumers

The following parameter were variabel:

- CAPEX
- Share of equity
- Basic fee per connection
- Revenue carbon credits

The aim was to have a low basic fee per connection and a high share of equity, with a prioritization given to the former. It is recommended that the remaining cash flow in the

scenarios - sum remaining after equity repayments and O&M costs - shall be invested into the community fund. This fund can then be used to finance energy efficiency measures or to support other activities within the camp (see section 5.2.8). In this way the money used to finance the grant will have a multiplier effect beyond providing financing for the initial installation of the PV-system.

The results

From an economical perspective the scenarios A1 and A2 are the most feasible. They allow the lowest basic fee of 15 USD/month to be paid by the consumers and enable a high share of equity (32% A1 and 68% A2). A basic fee of 15 USD/month is much less than households are currently paying and will create a high acceptance of the new electricity supply within the camp with a low risk of payment failures. As in scenario A1 and A2 the PV plant is connected directly to the public grid without a storage or back-up system meaning the O&M costs are more predictable. The technology is simple and easy to monitor and maintain, there are also no extra fuel costs for the diesel generator or high spare part costs for the battery.

Scenario A2 is even more economically feasible and can even be realized through 100% equity if the basic fee paid by the households is raised up to 20 USD/month, which is still less than the households are paying currently. In this case a corporate income tax needs to be considered. Therefore scenario A2b is calculated with a corporate income tax of 19%. As scenario A2b is functioning without external investment it would be a scenario which could be rolled out to other camps as well as in the region generally. However, as the technical feasibility depends on a higher electricity supply through the utility it is only feasible with strong political support.

| | A1 | A2 | A2b |
|---|---|---|---|
| Size of PV Plant | 16.6 MW | 6.9 MW | 6.9 MW |
| Total investment costs | 16,135,000 USD | 7,890,000 USD | 7,890,000 USD |
| Required amount of grant | 11,000,000 USD | 2,500,000 USD | 0 USD |
| Basic fee to be paid by the households | 15 USD/month | 15 USD/month | 20 USD/month |
| Revenues carbon credits | 170,038 USD | 170,038 USD | 170,038 USD |
| Cash flow available for the community fund during payback time equity | 87,659 USD | 186,896 USD | 69,339 USD |
| Cash flow available for the community fund after payback time equity | 764,705 USD | 903,749 USD | 1,127,198 USD |

**Table 19: financing PV plant in scenarios A1, A2, A2b**

Scenario B1 and B2 are also economically feasible, but they require a higher basic fee to cover higher operation and maintenance costs, owing to the battery storage and diesel back-up. For a 6A connection (scenario B1) the households would pay a monthly basic fee of USD 25 and

for the 4A connection (scenario B2) a monthly basic fee of USD 20, which is still less than the households are paying at the moment but the USD 25/month may be a struggle for the low income households and payment failures are more likely to occur. Therefore between the two scenarios B2 is preferable. B2 also allows for a higher share of equity with 30% and requires a lower grant. It is also provides the possibility for households to choose between a 4A connection for a basic fee of 20 USD/month or a 6A connection for a basic fee of 25 USD/month. The size of the required system would then need to be adapted.

| | B1 | B2 |
|---|---|---|
| Size of PV Plant | 11.5 MW | 6.9 MW |
| Size of Battery System | 6 MW | 4 MW |
| Size of Diesel Generator | 5 MW | 3 MW |
| Total investment costs | 17,140,941 USD | 11,496,706 USD |
| Required amount of grant | 13,500,000 USD | 8,000,000 USD |
| Basic fee to be paid by the households | 25 USD/month | 20 USD/month |
| Revenues carbon credits | 97,378 USD | 118,638 USD |
| Cash flow available for the community fund during payback time equity | 89,785 USD | 160,307 USD |
| Cash flow available for the community fund after payback time equity | 676,493 USD | 693,896 USD |

**Table 20: financing PV plant in scenarios B1, B2**

The scenarios C1 and D1 are not economical even with a high basic fee of 25 USD/month and a 100% grant financing. This is because of the high amount of diesel required to enable a 24/7 6A connection, if the supply schedule of the public grid is not changed.

The scenarios C2 and D2 are economically feasible but require a higher monthly basic fee for a 4A connection than option B2 and are only feasible with a low share of equity of 10%. So those scenarios are not recommended.

| | C2 | D2 |
|---|---|---|
| Size of PV Plant | 6.8 MW | 6.9 MW |
| Size of Battery System | 5 MW | 4 MW |
| Size of Diesel Generator | 3 MW | 3 MW |
| Total investment costs | 11,069,706 USD | 11,846,706 USD |
| Required amount of grant | 10,000,000 USD | 10,500,000 USD |
| Basic fee to be paid by the households | 22 USD/month | 25 USD/month |

| | | |
|---|---|---|
| Revenues carbon credits | 65,820 USD | 53,513 USD |
| Cash flow available for the community fund during payback time equity | 60,956 USD | 81,479 USD |
| Cash flow available for the community fund after payback time equity | 258,171 USD | 323,707 USD |

**Table 21: financing PV plant in scenarios C2, D2**

The following table gives an overview of all scenarios and the income of their financial model.

| | | Public Grid Parallel | | | | | | Seperate Grid Infrastructure | |
|---|---|---|---|---|---|---|---|---|---|
| | Schedule | Allways ON | | Night Schedule | | Typical Schedule | | Typical schedule | |
| Source | Unit | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| PRO & CON (Economical) | | economical very interesting: + low basic fee of 15USD/month + equity ratio 32% - required grant 11 Mio. USD | economical very interesting: + low basic fee of 15USD/month + highest equity ratio 68% + grant 2,5 Mio. USD | economical feasible, but: - basic fee 25USD / month - equity ratio 21% - required grant 13,5 Mio. USD | economical feasible: + basic fee 20 USD / month + equity ratio30% - required grant 8 Mio. USD | not economical | economical feasible, but: - basic fee 22USD / month - equity ratio 10% - required grant 10 Mio. USD | not economical | economical feasible, but: - basic fee 25USD / month - equity ratio 11% - required grant 10,5 Mio. USD |
| Total Investment | USD | 16,135,000 | 7,890,000 | 17,140,941 | 11,496,706 | 17,279,176 | 11,069,706 | 17,629,176 | 11,846,706 |
| Grant | USD | 11,000,000 | 2,500,000 | 13,500,000 | 8,000,000 | 17,279,176 | 10,000,000 | 17,629,176 | 10,500,000 |
| Equity | USD | 5,135,000 | 5,390,000 | 3,640,941 | 3,496,706 | 0 | 1,069,706 | 0 | 1,346,706 |
| Equity Capital Service (Interest + Principal) | USD/a | -674,307 | -707,792 | -478,114 | -459,173 | 0 | -140,469 | 0 | -176,844 |
| investment) | USD | 32% | 68% | 21% | 30% | 0% | 10% | 0% | 11% |
| Monthly Basic Fee for electricity | USD/connection /month | 15 | 15 | 25 | 20 | 25 | 22 | 25 | 25 |
| Operating Revenue | USD/a | 1,041,242 | 1,041,242 | 1,735,403 | 1,423,920 | 1,735,403 | 1,527,154 | 1,735,403 | 1,735,403 |
| Operating Expenses | USD/a | -457,469 | -325,549 | -1,139,151 | -845,915 | -2,241,072 | -1,334,425 | -2,171,116 | -1,462,160 |
| Revenue Carbon credits | USD/a | 170,038 | 170,038 | 97,378 | 118,638 | 0 | 65,820 | 0 | 53,513 |
| extra investment through high energy demand | USD/a | 35,598 | 35,598 | 35,598 | 35,598 | 35,598 | 35,598 | 35,598 | 35,598 |
| Cash flow (available for community fund) | USD/a | 87,659 | 186,896 | 89,785 | 160,307 | -616,561 | 60,956 | -500,017 | 81,479 |
| Cash flow (available for community fund) after payback of equity Capital Service | USD/a | 764,705 | 903,749 | 676,493 | 693,896 | -523,304 | 258,171 | -444,117 | 323,707 |

**Table 22: Costs and cash flow for the scenarios A1-D2**

### 5.2.7 Sensitivity Analysis

The model uses current market prices with an approximately 10% extra in order to compare the different scenarios and their economic feasibility. Once discussions with key stakeholders have determined which scenario has political support - and the precise technical capabilities are assured - the project team will develop a more detailed business proposal with a full sensitivity analysis.

### 5.2.8 Community fund

A key part of the proposed model is the creation of a community fund to facilitate low cost credit or gap financing support to additional energy-linked activities within the refugee and host communities. The fund will be financed initially through a proportion of the income from the sale of electricity during the period of equity repayments. Once the equity is repaid the fund will subsequently be financed through the positive project cash flow (see section 5.2.6).

Ensuring the sustainability of such a fund lies in good management and utilization where there is a clear entity/ body responsible. It is also important to consider the needs of the host communities that could be met using the fund and its mechanisms. This is essential for better integration and equity for local communities that live alongside refugees. For each type of fund use, the management structures would need to be developed.

The potential uses of the fund are broadly categorized in terms of

(a) Providing low-cost credit and targeted gap financing
(b) Catalyzing future innovation and ecosystem building

The section below outlines the different ways in which the resources in the fund can be used.

**Providing Low cost credit and targeted gap financing:**

The feasibility study highlighted the lack of financial linkage among residents of Domiz 1. This is mainly due to their current legal status as refugees which means they are unable to open a local bank account. Loans and financing are therefore provided informally through friends and relatives though with shops also regularly extended lines of credit to customers.

The community fund therefore aims to provide access to finance to residents, small businesses and institutions within Domiz 1. The community fund will be able to provide a number of targeted interventions the exact nature of which will be decided in consultation with residents. Examples of possible interventions and opportunities are further outlined below.

Here the target groups is largely individual households and small businesses, community facilities:

- Purchase of efficient appliances- at household or local business level that can reduce drudgery and enable judicious use of the renewable energy system
- Structural renovations to deal with mold, ventilation, thermal comfort improvements (currently some houses are experiencing see section on 'sick-home syndrome')
- Decentralized solar energy solutions for schools, health facilities, local businesses outside of the camp (in host communities) that face recurring power failures and high-cost of diesel based electricity

**Catalyzing future innovation and ecosystem building:** Going beyond the immediate needs of the community, there is a need for stronger ecosystem level activities that can catalyze future innovation and adoption of renewable energy solutions. This aspect could extend well beyond the community to look at Duhok and surrounding areas as well. Some opportunities in this regard include:

**Capacity building locally:** Resources to upskill and train more local technicians on appliance repair, spare part access, installation of renewable energy (beyond this camp), troubleshooting and regular maintenance of renewable energy solutions. Resources to also learn locally and share knowledge with more masons, construction workers on using local building material, efficiency-integration techniques, aspects of ventilation, lighting thermal comfort. This can be made available through existing vocational training institutions or through a separately organized training for skilled workers (plumbers, technicians, masons) within the camp.

**Catalyzing innovations:** This has a larger ambition of building ecosystems that are more responsive to decentralization, greening economies. The impact of these extend well beyond the camp and include:

- Building innovation and incubation hubs by supporting local schools, local universities, vocational training centers in the region with mentorship, tools, 'makerspaces' that can become hubs of innovation
- Seed funding to local entrepreneurs to develop prototypes- on appliances, energy systems, built environment components for household wellbeing, livelihoods, education, healthcare and so on
  Eg: affordable efficient motors to power small livelihood needs, or data monitoring systems for energy and appliance usage that integrate solar energy solutions

**Livelihood promotion and market linkages:** Subject to regulatory aspects, exploring local business development and livelihood promotion amongst small businesses and any farming communities. This could integrate energy for productive use and support could be provided for working capital for these institutions or more broadly building out market linkages and input-output supply chains based on the livelihoods prevalent in that region.

# 6 Conclusions and Recommendations

The report demonstrates the feasibility of implementing a sustainable energy solution within Domiz 1 based around the installation of a PV power plant. The study of the social, economic and technical situation within the camp has shown that there are no significant barriers to switching to a PV system that delivers increased electricity supply at a lower cost to residents, and that with political support a number of highly attractive options are available.

The most attractive options are scenarios A1 and A2 that do not require any diesel or battery back-up, however, these both require the utility operator to ensure that the public grid is always on. A1 would result in a significant surplus of electricity generated over the consumption of the camp which could feed-in to the national grid and also be used to supply other refugee settlements in the region. Strikingly, even within one of the most vulnerable communities within the country the study found there is a purely commercial option for transitioning from diesel to solar without the need for an upfront grant (scenario A2b). However, this would require an increase in supply from the national grid to ensure 24/7 electricity for the camp which might be politically and technologically challenging.

**Recommendations**

- Continue consultations with local, national and international stakeholders to determine which scenario is the most viable before producing a condensed project proposal to present to funders.
- Work with local NGOs to explore the governance structure of the future community fund and research potential projects/mechanisms that could be financed through the fund, especially in the area of energy efficiency.
- Develop a rigorous training concept for residents who will be involved in the installation of the PV system as well as outreach resources for residents clearly explaining the changes and also promoting energy efficiency.
- Outline a plan for the long term operation of the plant that includes a well-trained O&M team on site and regular monitoring by atmosfair.
- Initiate consultations with government and local PV businesses on legislative/guidelines for the integration of PV without storage into the national grid.
- Explore how to enable companies in the KRI to access innovative finance mechanisms like Carbon Credits and crowd funding.
- Identify further projects in refugee camps in the region that could be developed.