Promotion of Least Cost Renewables in Indonesia (LCORE-INDO)

Case Study: Solar Ice Making

Energy Efficiency and Solar PV concepts

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Executive Summary

Due to its unique geographic conditions as an island nation, Indonesia is one of the largest fish exporters in the world. Industrial fishing provides a sizable contribution to Indonesia's gross domestic product. In remote areas, long transport and inadequate cooling due to lack of ice often decrease fish quality and hence its market value. High solar irradiation in the eastern part of Indonesia offers a high potential for renewable energies to improve this situation. In cooperation with a company on Malukku, it's ice making process was analyzed in order to investigate the feasibility of solar power applications in the fishing and cooling sector.

This study shows the economic feasibility of energy saving measures and solar PV-driven ice making machine for 1 ton block ice per day. Based on a detailed simulation model, economic feasibility, different parameters such as diesel-fuel consumption and ice production frequency is evaluated.

Already small energy saving measures at the ice machine can reduce it's energy demand by 20% and larger optimization of the ice machine and process may reduce the energy demand by up to 40%. In addition, a reduced ice production time can be achieved. This results in a higher share of solar energy in the power supply. The ice production is shifted to daytime. Energy saving measures are highly attractive in areas with high diesel-fuel costs where payback times at around 3 years. Meanwhile, grid-connected ice machines are less attractive due to a low electricity tariff.

In the evaluated case, the following results were found: A 20kWp PV-system equipped with a 908 Ah battery bank is sufficient to power a one ton block ice production per day. In remote areas off-grid power supply, a payback period of 6 years can be achieved. Under the assumption of 50% grid-outages, the payback period increases up to 9 years. In areas with unstable PLN supply and fast supply improvements by the state utility, PV systems become less attractive due to cheap electricity tariff. Annual fluctuations in fishing activities and hence less ice production will affect the economic feasibility negatively. If the unused electricity in the case the ice machine is not operated, the feasibility can be improved if the excess energy is used domestically.

Contents

List of Abbreviations and Formula

AC	Alternating Current
Ah	Ampere hour
DC	Direct Current
DG-NREEC	Directorate General for New and Renewable Energy and energy conservation
E	Energy
EBITA	Earnings Before Interests, Taxes and Amortization
EUR	Euro
GA	Grid-Availability (in percent of the year)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IDR	Indonesian Rupiah
ILK	Institut fuer Luft und Kaeltetechnik (German research institute)
K	Kelvin
kg	Kilogram
kW	Kilo Watt
kWp	Kilo Watt-Peak
kWh	Kilo Watt-Hour
LCORE	Promotion of Least-Cost Renewables in Indonesia
P	Power
PLN	Perusahaan Listrik Negara (Indonesian State Utility)
PV	Photovoltaic
SF	Solar Fraction

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1. Introduction

Due to Indonesia's unique geographical conditions as an island nation with thousands of kilometres of coastline, the fishing industry contributes a sizable portion to Indonesia's gross domestic product. Besides fishing activities for domestic markets, industrial scale fishing which serves the export market with high quality fish provides an enormous value.

Generally fish destined for export market is processed in larger landing sites and in industrial scale processing units. Until the fish is processed and prepared for export, a long transport can affect its quality and therefore its market value.

In remote areas, inadequate energy supply and lack of ice production and cooling facilities seem to be the cause for quality losses, often affecting both local and export markets. Especially in the eastern part of Indonesia, lack of power supply and high energy production costs using diesel generators make renewable energies already competitive to conventional energy production. PV applications as new and innovative systems could be beneficial to increase the catch value through improved ice supply.

Furthermore, large fishing grounds in the Eastern part on Indonesia are still unexploited but offer large economic potential. Due to long transportation, exploiting these areas requires sufficient cooling directly at site. Since power supply in these areas is unreliable, not existing or dependent on costly diesel-fuel, decentralized solar energy can be a feasible power option.

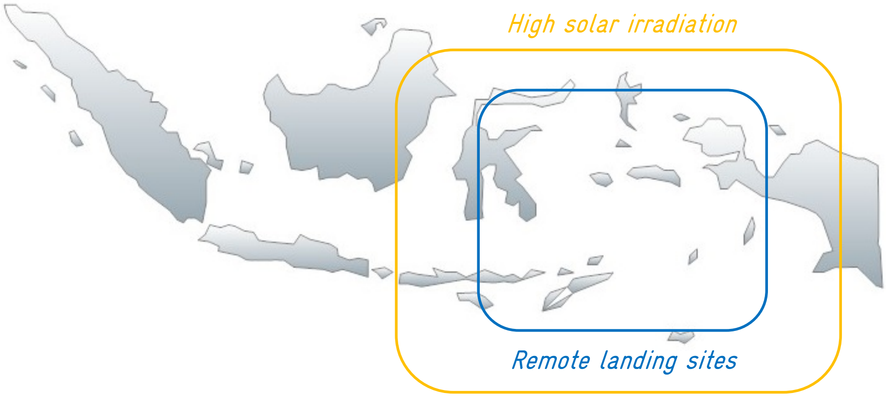

Figure 1: Map of Indonesia

The Indonesian Directorate General for New and Renewable Energy and Energy Conservation (DG-NREEC) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) have initiated the project 'Least Cost Renewables in Indonesia (LCORE-INDO)'. In the scope of this project, one specific goal is the assessment of a possible application of solar photovoltaic systems (PV) in the Indonesian fishing industry.

LCORE-INDO conducted several site visits to remote industrial landing sites and (industrial) fish processing in Malukku and Nusa Tenggara Timur province to identify the current state of the fishery value chain including social benefits for the fishermen. Especially in remote areas in the eastern part of Indonesia, detailed site visits in cooperation with a local NGO called MDPI (Masyarakat dan Perikanan Indonesia) identified a promising location for an off-grid solar-driven ice machine.

At the given location, long and frequent grid-outages affect the ice making production costs due to high diesel fuel usage for backup power. LCORE-INDO had signed MoU with a local block ice producer to develop a solar-driven ice machine and to investigate the financial and technical feasibility. The technical evaluation and financial modelling were conducted by the German Institut fuer Luft- und Kaeltetechnik (IKL), Dresden, Germay with on-site measurement support from national consultants and own calculations from LCORE advisors.

In the following chapters, the basics of block ice making are described to give a general understanding of the process and the impact of the current state of the ice machine on possible energy saving measures and PV-system configurations. The measurements which were conducted by a national consultant and further detailed investigations on scientific level, revealed an in-depth understanding on the existing ice machine efficiency. Ice production optimization potentials were identified and the impact on energy saving potentials and investment costs was assessed.

Four scenarios are considered to demonstrate the financial feasibility taking various parameters into account. This includes annual fluctuations in fishing activities, grid-outages, grid extension and improvements in the electricity supply. Understanding the main parameters that are influencing the feasibility of solar-driven ice machines and showcasing the implementation scenarios for an upscaling potential is the subject of this study.

2. Ice Making: Basics and current setup

2.1. Ice making basics

The schematic model of an ice machine is given in Figure 1. An ice machine for block ice production consists of a refrigeration circuit (blue) which is driven by electric components (red). The main components of the refrigeration circuit are compressor, condenser, evaporator and agitator.

The ice blocks are usually made from fresh or salt water filled in metal ice bins, which are placed inside the brine tank during ice making process. The brine tank contains a brine solution which is used for heat transfer in the ice making process. The brine is cooled down and the cold stored in the brine tank cools down the water inside the ice bins. As brine usually a salt water solution is used to reduce the freezing temperature of the brine to deep temperatures. During ice making process, temperatures between -10 and -20 degree Celsius are common. An agitator guarantees an equal temperature distribution of the brine to achieve an equal ice making progress.

An evaporator is located inside the brine tank through which a refrigerant is circulating. The refrigerant circulation is driven by a compressor in the refrigeration circuit which consists of an evaporator, a condenser and an expansion valve. The refrigerant evaporates at low temperature and vaporizes by taking the heat stored in the brine and thus the brine is cooled down.

The vaporized refrigerant is compressed by the compressor to a higher temperature and pressure. The heat is then released by the condenser to the environment. The vaporized refrigerant (high pressure) is released in the expansion valve to lower pressure and thus liquefies again. The process starts from the beginning.

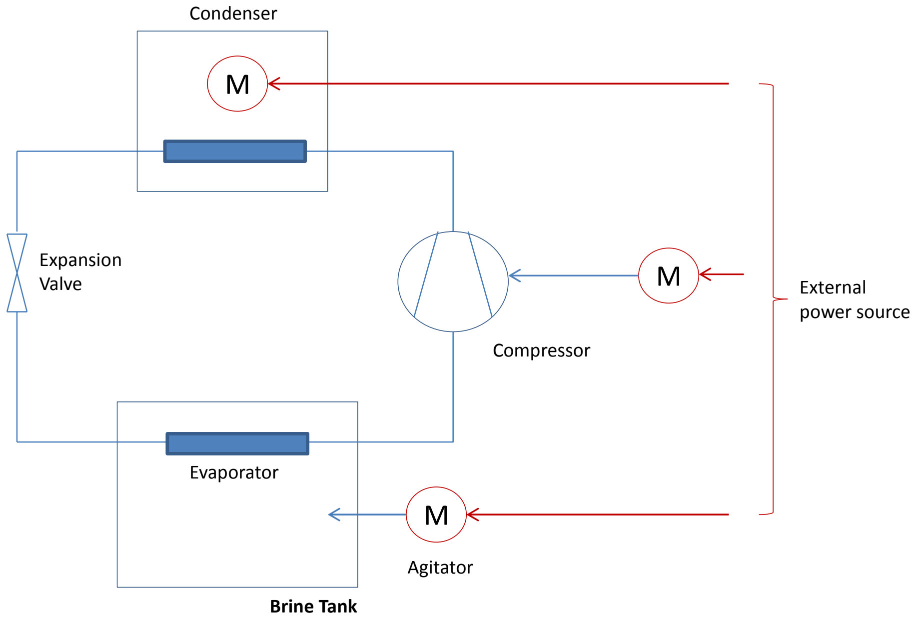

Figure 2: Schematic model of an ice machine referring to ILK Dresden

2.2. Current setup

The ice machine which is observed in this study is designed to produce 1 ton of block ice per day using fresh water supply. The electrical and physical parameters were collected during the measurement site visit and described in a separate report[1]

Ice bins

Motor, compressor and condenser

Brine tank

Evaporator

Figure 3: Ice machine

The ice machine is equipped with a 20.6 kWh thermal condenser and a 5.5 kW electrical compressor which are driven by an induction motor. Besides these main components, a 0.5 kW agitator brings an equal temperature distribution inside the brine tank during the ice making process. The brine tank is made of rigid polyurethane laminated with fiberglass and resin. As brine, saltwater (19% NaCl) is used. During ice making process, the brine tank is covered with wooden boards and plastic planes to reduce the heat ingress from the environment. Within the brine tank, ice bins filled with fresh water are placed during ice making process. The ice machine is currently operated using existing PLN connection. During grid-outages, the ice machine is operated using existing diesel generators. The main parameters are summarized in the following table.

Electrical Components			
Compressor	5.5	kW	Electrical
Condenser	0.8	kW	Electrical (measured)
	20.6	kW	Thermal
Agitator	0.5	kW	Electrical (measured)

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[1] PT. Anekatek Consultants (internal)

Total	6.8	kW	
	8.5	kVA	Cosphi 0.8 assumed
Brine Tank			
Brine Tank			
Brine	NaCl / water	19%	
Lenght	435	cm	
Width	140	cm	
Height	80	cm	
Ice Bins			
Height	50	cm	
Cross Section	20 x 10	cm^2	
Numbers	120		

Table 1: Ice machine setup

3. Ice Machine: Current state

The following chapter describes the current state of the existing ice machine. In Indonesia's fishery industry, ice machine set-ups are usually hand-made configurations equipped with components from international manufacturers. These system configurations offer a potential to evaluate both the state of existing ice machine setups and the energy efficiency measures in order to minimize the solar PV system size as well as improving the energy demand and ice making time.

In order to identify the current state of the ice machine, measurement instructions were defined in cooperation with the German research institute ILK Dresden and measurement instructions were conducted by a national consultant. The results are described in detail in a separate report[2].

Based on the measurements and on-site parameter collection, a detailed mathematical model was developed by ILK to investigate the influence of electrical and thermal parameters on the ice making process. Its accuracy could be verified based on the measurement results. In the frame of this study, the main findings will be summarized as a basis for the economic feasibility calculations.

The efficiency of an ice machine mainly consists of two components: External heat ingress and heat ingress due to electrical losses of the agitator (1) and an optimized refrigeration setup of the compressor, evaporator and condenser (2).

The thermal losses were estimated by a time series of ambient temperature and the brine temperature during heating up while the agitator was running.

The measurements show, that the thermal insulation is sufficient. The thermal losses due to external heat ingress are therefore needs not to be optimized.

Furthermore, based on on-site data collection such as brine solution, brine tank dimension, refrigerant and the operation characteristics of the condenser and compressor, a dynamic simulation model was developed.

A measurement during the cooling down of the brine was taken to estimate the cooling power of the ice machine. Combined with the thermal losses as described above, a simulation model of the ice making machine was developed.

By conducting parameter-fitting (temperature and pressure assumptions of the refrigeration circuit), the simulation result could be fitted to the measurement. As a result, a detailed model of the specific ice machine was developed.

The parameter fitting shows that the tuning of the refrigeration circuit is not optimal. Several reasons can cause this which needs further investigation of the temperature and pressure conditions of the refrigeration circuit. Furthermore, the operation point of the condenser and the compressor are not optimum based on estimated temperature levels and condenser/compressor characteristics.

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[2] ILK Dresden (internal report)

The refrigeration circuit is not running in an optimal operation point. The pressure end expansion valve need to be investigated more detailed and temperature levels need to be adjusted.

Adjustment of the temperature requires adjustment of the compressor / condenser operation point.

In this chapter, the state of the existing ice machine was identified. Therefore, detailed measurements were conducted and a mathematical simulation model derived which could be verified based on the measurements.

Under current conditions (existing compressor and condenser characteristics) and estimated temperature parameters of the refrigerant, an electric energy demand of 100 kWh per ton was calculated. The average ice making time was calculated to be 15 hours per ice making cycle.

Whereas the thermal losses which are mainly given due to environmental heat ingress are in good condition, the refrigeration unit is not running in an optimal point. To optimize the efficiency of the ice machine, several optimization measures are proposed in the next chapter.

Current ice making requirements:

- 36.000 kWh/ton
- 15 hours per cycle (compressor operation time)

4. Ice Machine: Optimization potential

As it was described in the previous chapter, the measurement results and the simulation model revealed various optimization options as the refrigeration system is not running in an optimal state.

Based on the findings, an improved and an optimized ice machine can be defined (Figure 4).

For all scenarios, the adjustment of the refrigeration circuit is mandatory. The consultancy costs amount to 1000 EUR (scenario 1). For an optimized ice machine (scenario 2), a new condensing unit needs to be installed (6000 EUR). These optimizations / improvements can be considered as mechanical / electrical improvements.

For a more advanced optimization, a reduction of the ice bin cross section can be considered (scenario 3). The ice making time, and thus the energy demand highly depends on the ice bin cross section but might be disadvantaged to existing infrastructures and manageability during transport.

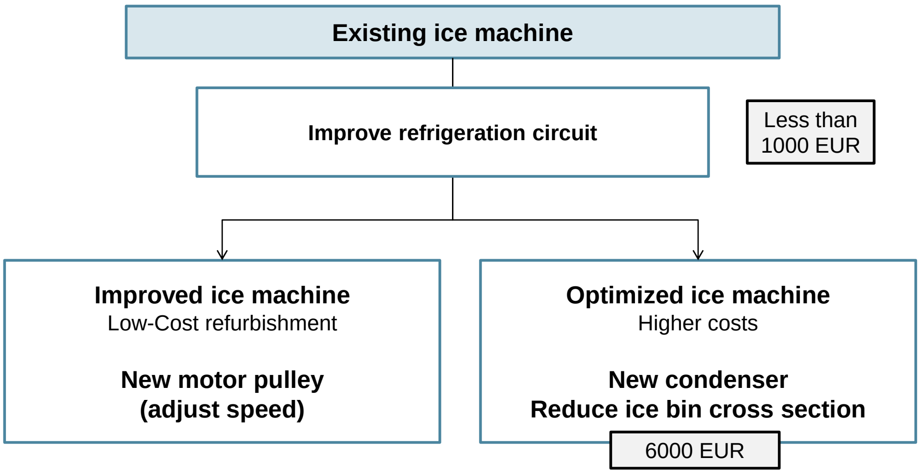

Figure 4: Optimization of the existing ice machine

The results are summarized in Figure 5. Already small adjustments in the refrigeration circuit and motor speed adjustment by replacing the motor pulley can lead to an energy saving potential of up to 20% (scenario 1). A new condensing unit increases the saving potential to 30% (scenario 2). Adjusting the ice bin cross section from 20x10 cm^2 to 20x5 cm^2 will result in the maximum saving potential of 40% (scenario 3).

Respectively, improvements and optimization influence the ice making time (read: when the compressor is running) in a positive way. For the improved ice machine, an average ice making time (1 ton block ice) with the given electrical equipment of 15 hours can be expected.

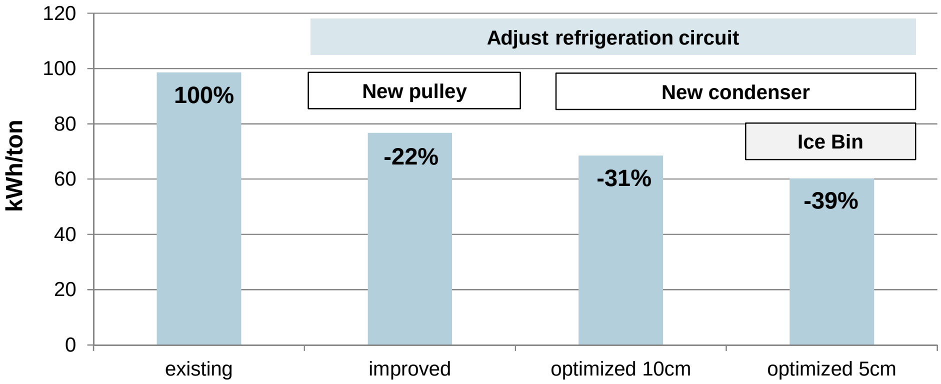

Figure 5: Optimization potential of different adjustments compared to the existing ice machine

For the optimized (existing and reduced ice bin cross section), an average ice making time of 10 hours and 8 hours respectively are to be expected.

Besides a faster block ice production, a reduced ice making time leads to a higher share of solar energy usage during daytime which is discussed in the following chapter.

Based on given requirements at site (manageability of the ice blocks during transport), a reduction of the ice bin cross-section is not possible. However for a complete comparison of different optimization models, this option will be investigated in the following chapter as well.

Improved ice machine

- Investment 1000 EUR
- Energy saving 20%
- Ice making time 15h

Optimized ice machine (20x10 cm^2 cross section)

- Investment 7000 EUR
- Energy saving 30%
- Ice making time 10h

Optimized ice machine (20x5 cm^2 cross section)

- Investment 7000 EUR (ice bin modifying costs neglected)
- Energy saving 40%
- Ice making time 8h

5. Solar PV concepts and simulation results

Within this study, an off-grid system with diesel-generator or optional PLN backup is pursued. As under current conditions the power supply is provided by a local PLN grid, a full off-grid operation is not given. During the time of grid-outages, an off-grid system is intended. When PLN grid is available, the system can be operated as fuel saver or net-metering system to decrease the factory domestic energy consumption.

In Figure 6, the general setup is shown. During ice making, the ice machine is driven by a PV-diesel hybrid system (left). During the time when the ice machine is not operated, the PV system can directly be connected to the ice factories domestic grid (right).

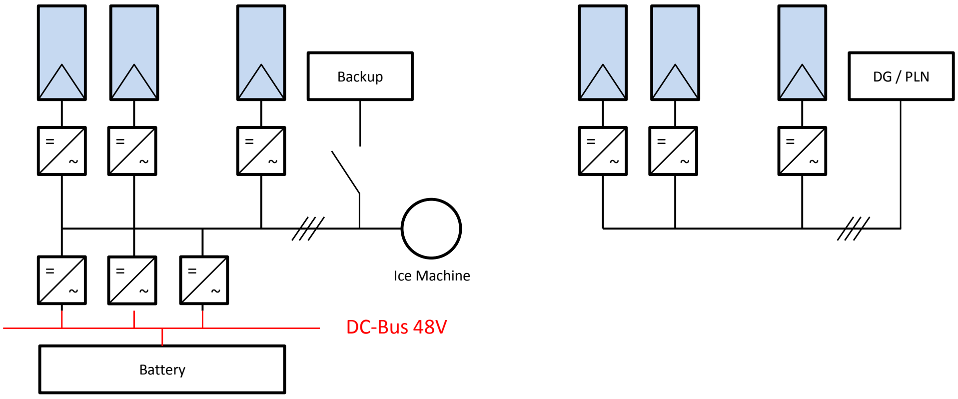

Figure 6: PV concepts for ice making (left) and factory demand (right)

During high solar irradiation, the ice machine will be operated mainly using solar energy. During periods of low irradiation, battery banks will provide the remaining energy until the maximum allowed discharge level is reached. In this case, an external power supply such as diesel generator or an existing PLN connection will provide the remaining power and recharge the batteries.

Based on the measurements and the simulation model as described in the previous chapters, different system configurations were compared[3]. Different PV and battery capacities were simulated to investigate the impact on the share of solar energy usage (solar fraction), battery lifetime and required backup energy. Among others, these parameters are used as input parameters for the economic feasibility calculations which will be described in more details in chapter 6.

The simulations were done using location-specific environmental database parameters[4] as well as electrical and thermal parameters to receive the overall energy demand per ton of ice for different system configurations.

A simulation of ice making cycle is shown in Figure 7: The ice machine (green line) is operated daily with an average capacity of 6.8 kW. During the first period, the energy from the PV panels and required additional energy from the battery bank can fully supply the ice making. On the third day, the solar irradiation is not sufficient and thus the battery discharges faster. Once the maximum deep discharge level is reached, the backup power source is switched on to supply the ice making cycle and recharge the batteries.

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[3] ILK Dresden (internal report)

[4] Meteonorm 6.1. Solar irradiation for given location: 5.5 $kWh/m^2/day$

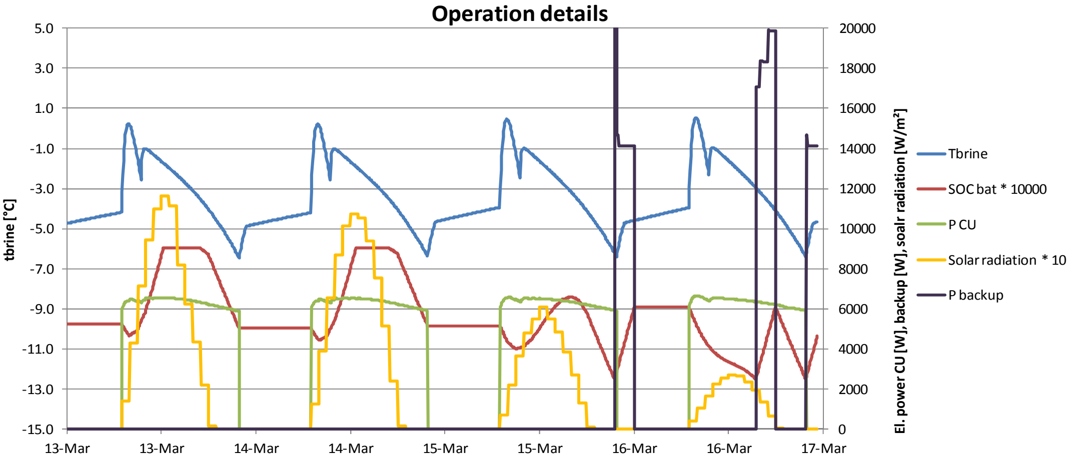

Figure 7: General simulation results for a solar-driven ice machine (ILK Dresden)

The blue line in Figure 7 describes the brine temperature during the ice making procres. At the beginning of each ice making cycle, the brine temperature increases as new fresh water is filled in the ice bins and the cold stored in the brine is used to cool down the water. The compressor operates at full capacity and continues to cool down the brine. At the freezing point of the water, the brine temperature increases. The ice making cycle continues and after shutting down the compressor, the ice making cycle is finished by using the cold stored in the brine.

Table 2 shows the main simulation results for selected system configurations. In the following study, the optimized ice machine with 20x10 cm^2 ice bin cross section will be used as reference. The detailed study by ILK Dresden revealed different system configurations leading to a sufficient PV capacity of 20 kWp for the optimized ice machine and to demonstrate a high solar fraction using a large battery capacity.

For the existing ice machine, an annual energy demand of 36.000 kWh per year was simulated. By using the reference system as described above, a solar fraction of 60% can be achieved leading to an annual backup energy demand of 14.000 kWh. Small improvements will increase the share of solar energy for the given configuration to 70% (8.500 kWh back up energy per year). For the optimized ice machines, a solar fraction above 90% can be reached (90% for 20x10cm^2 respectively 94% for 20x5 cm^2 ice bin cross section). Besides a higher energy demand, smaller optimization leads to a longer ice making cycle. As the PV and battery capacity are kept constant for the reference system (20 kWp, 908 Ah battery), the required battery energy during the day increases, effectively reducing the battery lifetime.

	Existing	Improved	Optimized 20x10	Optimized 20x5
Energy demand /kWh/year	36.000	28.000	25.000	22.000
Backup Energy	14.000	8.500	2.500	1.500
Solar Fraction	60%	70%	90%	94%
Battery Lifetime	3	4	9	14

Table 2: Different PV-system specifications (20 kWp, 908 Ah) (red: reference system)

6. Economic Feasibility

6.1. Background

The results of the detailed technical simulation conducted by ILK Dresden are summarized in chapter 4 and 5. The investment for the PV system consists of the PV-System itself and additional refrigeration components in case of an optimization of the refrigeration circuit.

The economic feasibility is calculated based on the flowchart in the figure below and will be discussed in the following more detailed.

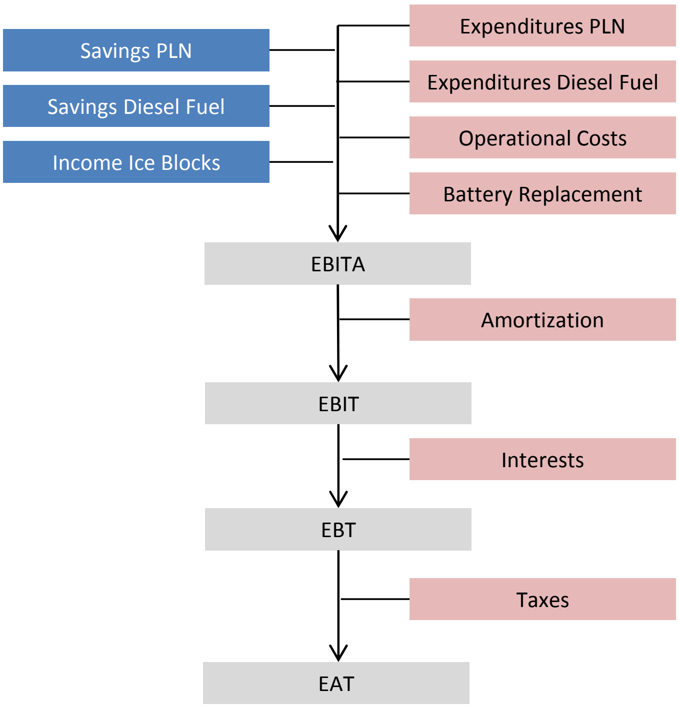

Figure 8: Simplified calculation of the economic feasibility

Energy Parameters

For the calculations of the economic feasibility several parameters are taken into account. As described in the chapters before, the energy situation in the given location still suffers grid-outages up to 50% of the day. Under the current PLN tariff (972 IDR/kWh during off-peak time) a solar PV system might not be economically feasible, whereas under back-up operation when expensive diesel fuel is used, solar PV options are economically promising.

As described in chapter 5, based on different Solar PV concepts, a conventional backup (diesel generator or existing PLN connection) is necessary to ensure continuous operation as a function of the expected solar fraction of the ice machine.

As in Indonesia's fishery industry, annual high season and low season affect the fish catch volume and thus the expected ice demand. Thus, an annually continuous operation of the ice machine is not necessary as the financial feasibility and payback time of the investment will be negatively affected. Under the assumption of a high domestic energy demand of the factory, an additional saving can be achieved using net-metering or diesel-fuel saver during the time the ice machine is not operated.

In order to illustrate these scenarios, the expected savings (share of Solar PV usage, blue) and expenses (energy during backup operation, red) are modelled according to the figure below.

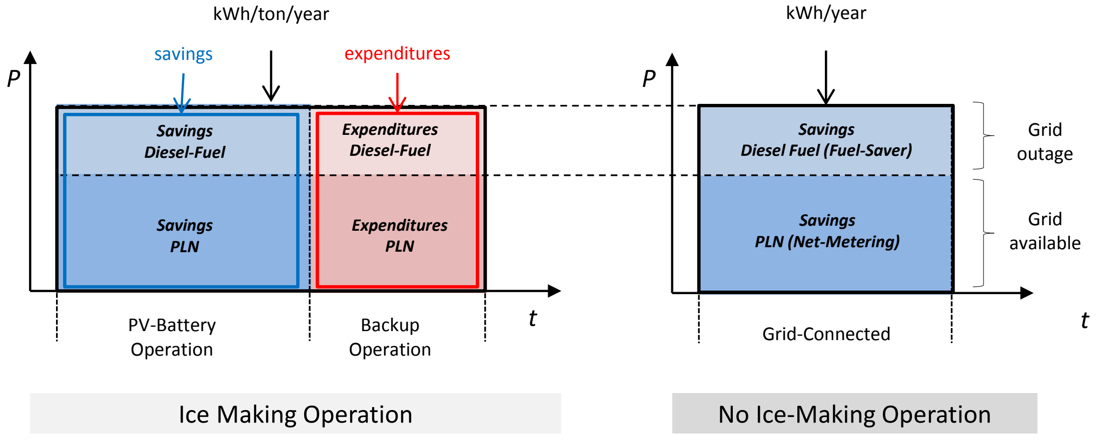

Figure 9: Energy Balance during Ice-Making and Non-Ice-Making Operation

The savings during ice making operation (blue shape, Figure 9 left) can be calculated as a function on the solar fraction of the solar-driven ice machine (solar energy usage) as well as expected expenditures during backup operation either provided by diesel-generators or PLN (red shape, Figure 9 left).

Under current conditions, grid-outages are common and frequent and thus this situation has to be taken into account. As the intended PV system under ice making operation will demonstrate off-grid operation, the savings and the expenditures furthermore depend on the ratio of grid-availability during off-grid operation.

During the time the machine produces ice, the total savings depend on the assumption of saved diesel fuel or PLN tariff in the ratio of the grid-availability. The expenditures during backup operation result from spent diesel-fuel and PLN tariff respectively (red shape).

During the time the ice machine is not operating, the PV system can be connected to the ice factory domestic power supply and can be operated as “grid-connected” PV-system. During this time no backup energy is needed as can be seen in Figure 9 right), and the produced energy based on the specific solar energy yield (1300 kWh/kWp assumed) will either reduce PLN tariff expenditures or diesel-fuel.

The considered life-time of the ice machine is 20 years. The current PLN grid-availability of 50% might not be constant during this period as PLN grid-extension and energy generation will improve. An assumed high share of saved diesel-fuel in case of grid-outages in the beginning of the system implantation might decrease drastically and thus influence the economic feasibility due to an increasing share of cheaper PLN tariff (Figure 10).

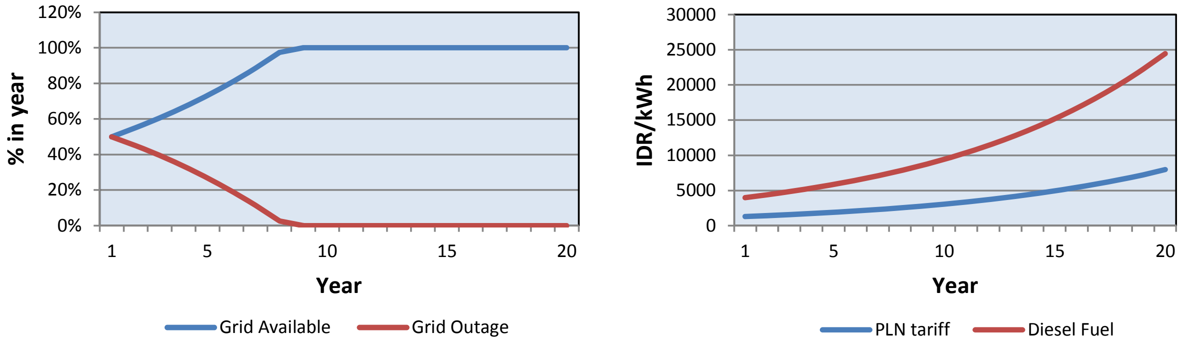

Figure 10: General Tendencies Grid Availability (left) and Diesel-Fuel and PLN Tariff Increase (right)

For the economic calculations, a current diesel-fuel price of 11.500 IDR/liter and a PLN tariff B2 (972 IDR/kWh[5]) are assumed with an annual price increment of 10%. Based on the derivation above, the saving and expenditure balance can be summarized as follows:

Ice machine operation

Savings (Solar PV usage)

- E_{ice} SF t_{ice} GA c_{PLN}
- E_{ice} SF t_{ice} (1-GA) c_{Diesel}

Expenditures (Backup operation)

- E_{ice} (1-SF) t_{ice} GA c_{PLN}
- E_{ice} (1-SF) t_{ice} (1-GA) c_{Diesel}

Own consumption

Savings (Solar PV usage)

- E_{PV} (1-t_{ice}) GA c_{PLN}
- E_{PV} (1-t_{ice}) (1-GA) c_{Diesel}

Where E_{ice} is the annual energy demand for ice production, SF is the solar fraction, GA the grid availability, t_{ice} the annual share of ice production and c_{PLN} and c_{Diesel} to costs per kWh for PLN tariff respectively diesel-fuel. For own consumption, E_{PV} is the expected energy yield (kWp/kWp)

Operation and Maintenance

In the section above, the savings and expenditures for diesel-fuel and/or PLN tariff are derived. Additional expenses due to operation and maintenance must be considered.

General operation and maintenance costs (O&M) as regular maintenance and management costs are assumed to be 10 EUR/kWp per year.

In addition, based on the desired share of solar energy usage (solar fraction) and backup energy, the battery capacity will both affect the respective quantities as well as the size and especially lifetime of the battery. Larger battery banks increase the lifetime and the solar fraction positively

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[5] Off-peak during daytime

whereas the initial investment will increase. Smaller (initially more feasible) battery banks will decrease the lifetime and thus regular and more frequent battery replacement is necessary.

Financial Parameters

To equip the existing refrigeration unit with a PV-Battery system or to invest into an optimized ice machine requires initial investment costs of about 40.000 to 50.000 EUR depending on the intended solar fraction and thermal refrigeration optimization. Due to these high costs, a bank loan for financing the project might be required.

To consider the loan in the economic feasibility calculations, the payback of the loan is assumed to use annuity approach, stating the sum of loan redemption and interest are constant over the payback period.

The annual annuity can be calculated under consideration of the payback period t_P, required loan L and interest rate I using:

$$\text{Annual Annuity} = \frac{L\,I(I+1)^{t_P}}{\left((I+1)^{t_P}-1\right)}$$

As the energy produced by the solar system will – in contrast to a FIT scheme – not be sold to the state utility and thus generating revenues, taxes are neglected.

6.2. Economic feasibility of energy efficiency measures

The results of ILK Dresden revealed that besides the solar PV potential, energy efficiency measures are also promising to be implemented (both to decrease the energy consumption and to reduce the PV system size). In a first step, a general improvement of the refrigeration circuit can reduce the energy demand per ton of ice by 20% with an assumed consulting cost of 1000 EUR.

Additional investment in a more efficient condensing unit (6000 EUR) and a modification of the ice bin cross section can reduce the energy demand by 30% respectively 40%. Additional manufacturing costs for ice bin modification are neglected.

Table 3 summarizes the numbers for the three observed ice machine improvements for 1 ton block ice production per day.

	Improved ice	Optimized	
		20x10 cm^2	20x5 cm^2
Investment costs / EUR	1000	7000	7000
Annual energy demand / kWh	28.000	25.000	22.000

	PLN	Diesel fuel
Cost	972 IDR/kWh	11.500 IDR/liter
Cost increase per year	10%	10%

Table 3: Parameters for economic feasibility calculation (energy efficiency)

In the following, the extreme values of 100% diesel usage and 100% PLN grid-availability are compared to give a general understanding of the economic feasibility of energy saving measures. Based on the previous chapters, the improved ice machine only considers consulting service for refrigeration circuit optimization whereas the optimized ice machine include a new condensing unit and respective ice bin cross-section modification.

Figure 11 shows the accumulated cash flow for a scenario if 100% diesel fuel is used to produce block ice. A comparable cheap investment for consultancy service will pay back in the first year and will accumulate to an overall saving of 40.000 EUR after 20 years. A payback of 2 to 3 years are to be expected in case of an additional investment of 6000 EUR (7000 EUR total) for an optimized ice machine, resulting in 50.000 respectively 65.000 EUR savings after 20 years.

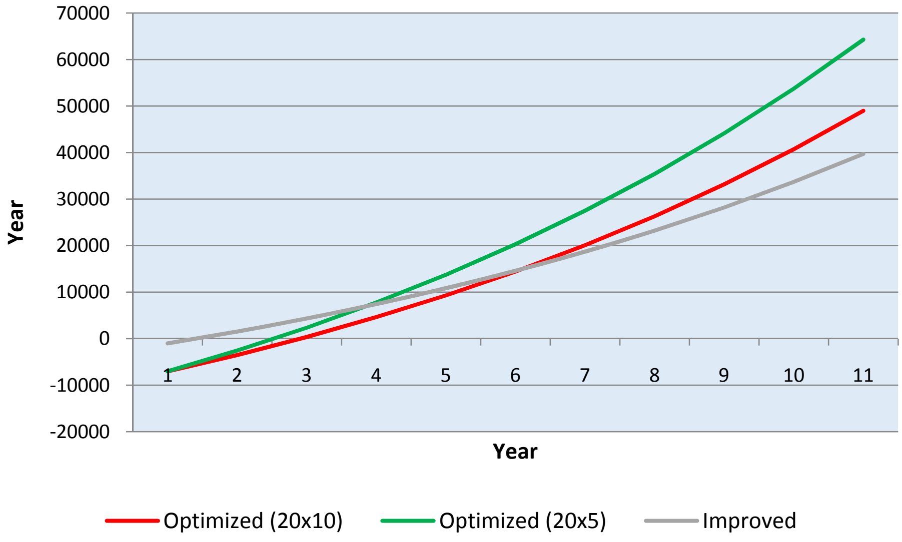

Figure 11: Accumulated Cash-Flow (100% diesel usage, 10% annual price increase)

For 100% off-grid systems, an optimization of the ice machine should be considered.

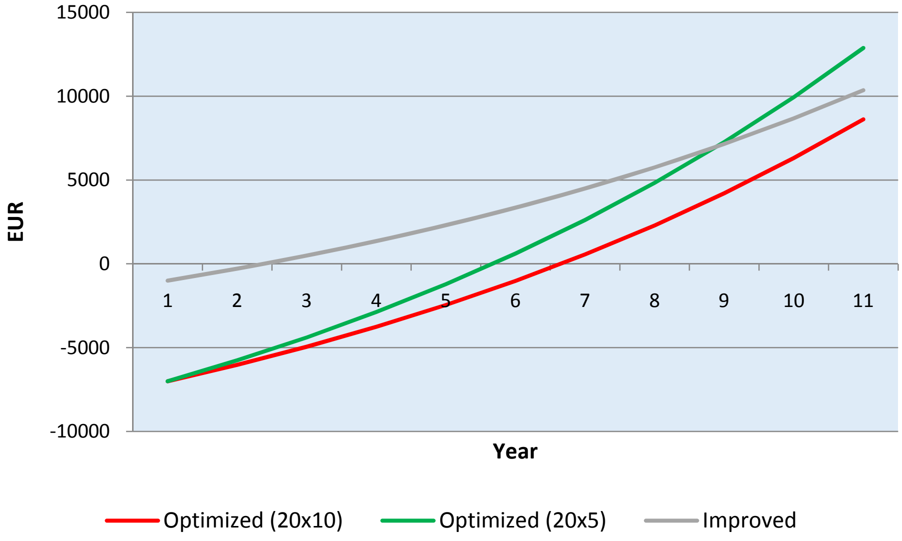

Figure 12: Figure 9: Accumulated Cash-Flow (100% PLN usage, 10% annual price increase)

In Figure 12, the scenario for 100% PLN availability is shown. Due to the current comparable low electricity tariff, the expected payback time generally increases.

For the improved ice machine, an expected payback period of 2 years and an accumulated cash flow after 20 years of 10.000 EUR can be expected. Compared to the scenario discussed above, a payback period of 2 years is still reasonable, but smaller profit must be expected.

For larger investments (optimized ice machine) the payback period increases drastically to 5 respectively 6 years even if an annual PLN tariff increase of 10% is supposed. The accumulated cash flow amounts to 7.000 EUR respectively 12.000 EUR. As it can be seen, an optimization with a comparable high investment for optimization alone is less feasible than a smaller investment for improvement (consulting service costs) to the highly subsidized PLN tariff.

Nevertheless, an optimized ice machine will decrease the overall investment costs and system sizing as described in chapter 5 if a solar PV option is implemented. In the following chapter, the optimized ice machine will be used as a reference scenario.

A simple **improvement** of the refrigeration circuit is feasible both for high share of diesel fuel and PLN usage. A **payback of maximum 2 years** can be expected, **saving of around 20%** of the energy demand for ice making.

An **optimized** ice machine is **feasible for off-grid** systems with an expected **payback of 2 to 3 years** with an expected energy saving potential of 30% respectively 40%.

6.3. Economic feasibility of Solar PV options

In the previous chapter, the economic feasibility of possible energy saving measures for different system improvements was investigated. It could be shown, that especially for off-grid application, larger energy saving investments can be reasonable, which also affect the system size positively.

In this chapter, the economic feasibility of a solar-driven ice machine will be conducted. The calculations are based on the defined optimized ice machine with the existing ice bin cross-section of 20x10 $cm^{2.}$ as reference. It has to be mentioned that under unique environmental conditions and annual fluctuations in ice block demand, other system configurations might be more reasonable, especially when no daily ice production is possible or necessary.

The study conducted by ILK Dresden revealed, that a 20 kWp system equipped with a battery bank of 908 Ah will ensure around 90% solar fraction of the annual energy demand of the optimized ice machine (daily ice production assumed). The investment costs amount to 47.000 EUR and a battery replacement of 8800 EUR every 9 years. This system will be used as a reference.

The economic feasibility is calculated based on the description in chapter 6.1. The parameters used in these calculations are summarized in the tables below.

Diesel Fuel	11.500 IDR/liter	Loan / Equity	70%/30%
Diesel Fuel incr.	10% p.a.	Loan period	10a
		Loan interest	15% p.a.
PLN	972 IDR/kWh		
PLN incr.	10% p.a.	Exchange rate	12.000 IDR/EUR

Table 4: Fixed parameters

	Existing	Improved	Optimized 20x10	Optimized 20x5[6]
Investment costs[7]	40.000	41.000	47.000	47.000
Battery Lifetime	3	4	9	14
Battery replacement costs	8.800	8.800	8.800	8.800

Table 5: Investment costs for different configurations

In the following, different ice machine optimizations are compared. As mentioned above, the reference system will be based on a 20 kWp system equipped with 908 Ah battery bank.

Figure 13 shows the accumulated EBITA of the different ice machine setups for daily ice block production and assuming grid-outages are not given (100% PLN supply). Due to the fact that in this case an intended solar-driven ice machine will be paid back with saved PLN electricity costs, the existing ice machine and an improved concept are not economic feasible. The current cheap electricity tariff and high battery replacement costs (steps) do not allow feasible configurations.

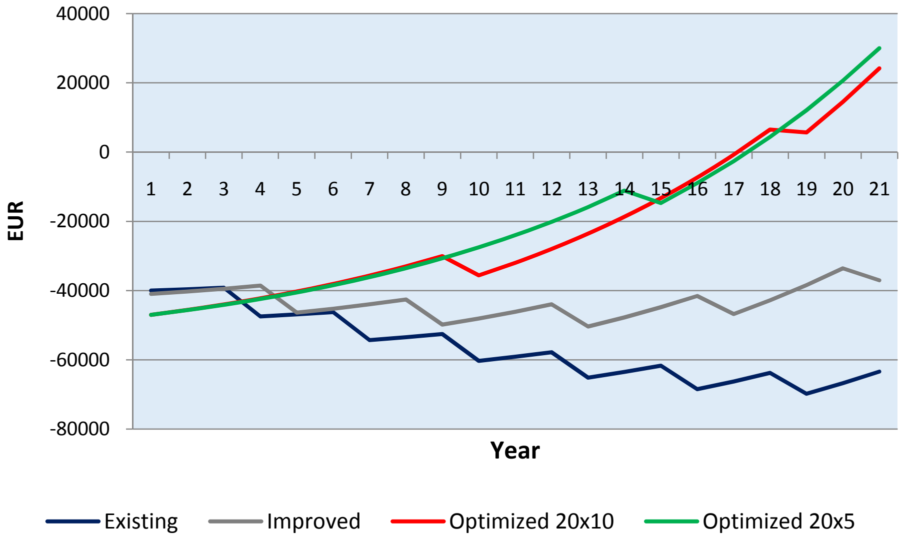

Figure 13: EBITA (accumulated) for different ice machine setups (daily ice production, 100% PLN electricity usage)

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[6] Costs for ice bin modification neglected

[7] This number includes only costs for PV-system, battery and condenser. Compressor costs are neglected.

The optimized ice machines (with new condensing unit) as described in the previous chapter offer significant energy saving measures resulting in lower energy demand and higher battery lifetime. For the optimized ice machine setups, a payback after 16 years can be expected.

As lower energy demand results in lower electricity saving potential, these numbers are in contrast to the results shown in the figure above. Higher economic feasibility with comparable equal investment costs for all system configurations can generally be obtained if it were not because of battery replacement costs which render some configurations economically unfeasible. It can be seen in Figure 12 that regular battery lifetime replacement affects the profitability of the project negatively when in general, a positive payback trend is clearly evident.

In Figure 14, the economic feasibility is described in case of 100% diesel-generator usage.

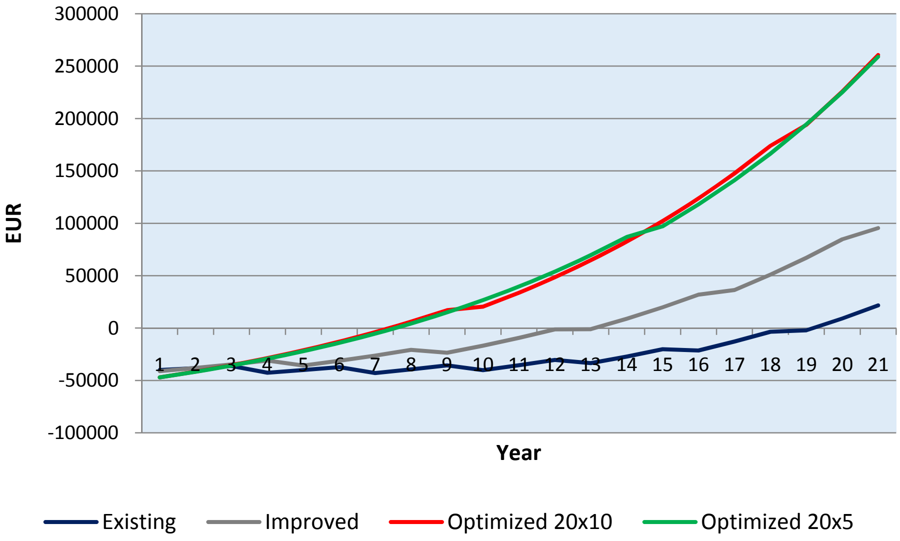

Figure 14: EBITA (accumulated) for different ice machine setups (daily ice production, 100% diesel generator usage)

Due to a comparable high diesel fuel price of 11.500 IDR per liter (around 3500 IDR/kWh[8]) compared to the current PLN electricity tariff (972 IDR/kWh), the economic feasibility increases drastically.

The payback time for the existing and improved ice machine increase to 19 respectively 12 years. The negative impact of frequent and expensive battery replacements can be compensated compared to the previous case.

For a higher investment in energy saving measures (optimized ice machine with 20x10 cm^2 respectively 20x5 cm^2 ice bin cross section and new condensing unit), the payback time increases to 7 years and results in an accumulated saving of 250.000 EUR. Furthermore, it can be seen that the difference between the ice bin cross sections does not significantlt affect the feasibility. Smaller ice bin cross section and resulting energy demand lead to smaller diesel fuel savings and thus smaller increase of the curve. Compared to the larger ice bin cross sections and higher energy demand / savings, the more frequent battery replacement costs lead to an approximately equal feasibility after 20 years lifetime.

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[8] Generator efficiency of 33% assumed

Summarizing the findings above, ice machines can be considered as promising options for solar PV applications in areas with 100% or high diesel fuel usage, which also includes new catch areas with lack of diesel supply. Nevertheless, a well optimized system configuration based on the ice demand and solar fraction must be in place.

In the observed case, both daily ice production and a full energy supply of PLN or diesel fuel is not given. In order to investigate the influence of dynamic parameters such as grid availability and fluctuations in annual ice block production, a reference system (20 kWp, optimized ice machine with 20x10 cm^2 ice bin cross section) was chosen.

In a first step, the initial and increasing grid-availability are investigated. Based on experiences, the local grid-availability is 50% per day. As a result it can be stated, that 50% during ice making time, backup energy from diesel generator is necessary. Figure 15 shows the economic feasibility as a function of different grid-availability increments.

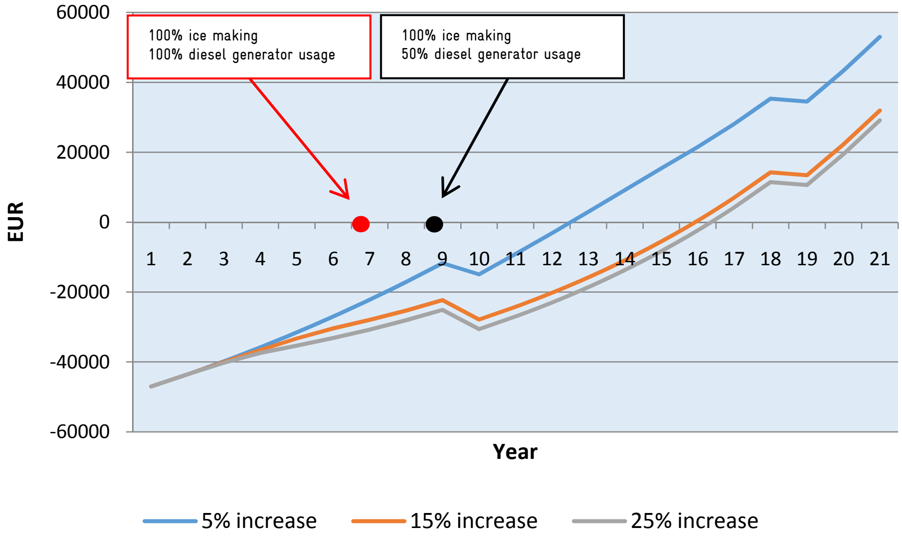

Figure 15: EBITA (accumulated) for different grid-availability increments (50% initial grid-availability)

As described in the previous scenario, 100% off-grid operation would result in a payback time of 7 years for reference system (100% ice making, 100% diesel-generator usage, red point in Figure 15). Assuming a constant grid-availability of 50% over the project lifetime, the payback period already increases to 9 years due to cheap (but increasing) electricity tariff (black point).

As a constant grid-availability of 50% average cannot be assumed, the annual savings to pay back the system will be subjected to higher share of PLN electricity. As a result, already 5% grid-availability increase per year increases the payback time to 13 years. Faster improvements in grid-availability (15% respectively 25%) result in payback times over 15 years.

To compensate a grid-availability increase of 15%, a PLN electricity tariff increase of 25% per year would be necessary.

Besides constant grid-availability, constant ice machine operation might not be given as well, influenced by seasonal fluctuations in fishing activities or less ice demand due to unknown reasons. As the payback of the ice machine relies on saved diesel duel / PLN electricity used when the machine would have been operated, unused energy will affect the economic feasibility negatively.

In the following, 50% ice making during the year is assumed, which means the ice machine is only 6 months per year operated. As described in chapter 5, during the time the ice machine is not operating, the unused energy can be used for domestic energy supply[9]. In case of a stable PLN connection (100% grid-availability) a net-metering system results. In case of 100% diesel-fuel usage, a fuel saver concept is given. In the following, the definition *with* and *without* describe the case if the unused energy can be used domestically or left to waste.

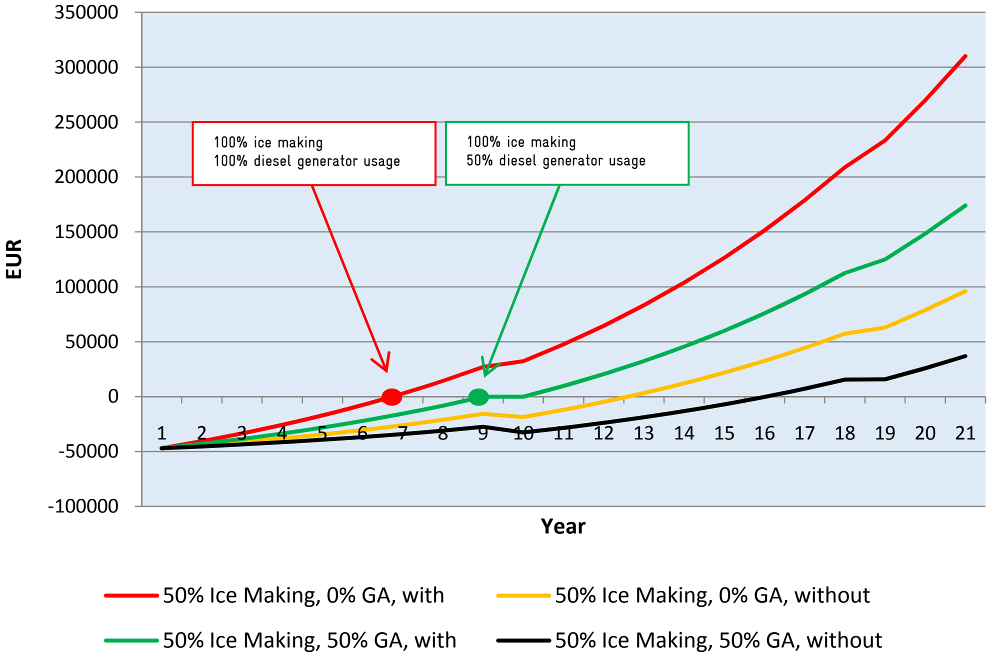

Figure 16: Impact of ice making time on economic feasibility with and without domestic energy usage possibilities

As it was shown in the section before, 100% off-grid under the assumption of daily ice block production led to a payback time of 7 years (Figure 16, red point). A grid-availability of 50% (no grid improvements assumed) led to a payback time of 9 years (green point).

The red curve shows the economic feasibility in case of 100% off-grid operation. As mentioned above, a payback time of 7 years is given in case of daily ice production. In case the ice machine is only operated 50% during the year (average) but the unused energy produced by the PV system can be used domestically, a non-continuous production can be fully compensated. In case, no domestic energy supply is possible, the payback time will increase to 12 years (orange line).

Respectively, for 50% grid-availability, the payback period of 9 years (green point 100% ice production, green line 50% ice production, domestic supply possible) can be compensated using PLN tariff / diesel-fuel savings. In case no domestic energy supply is given, the payback period increases to 17 years.

The effects of grid-availability and annual average ice production which were discussed in this chapter can be displayed in the following figure based on a 50% initial grid-availability (10% increase per year) and 50% ice making.

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[9] 1300 kWh/kWp annual energy demand assumed

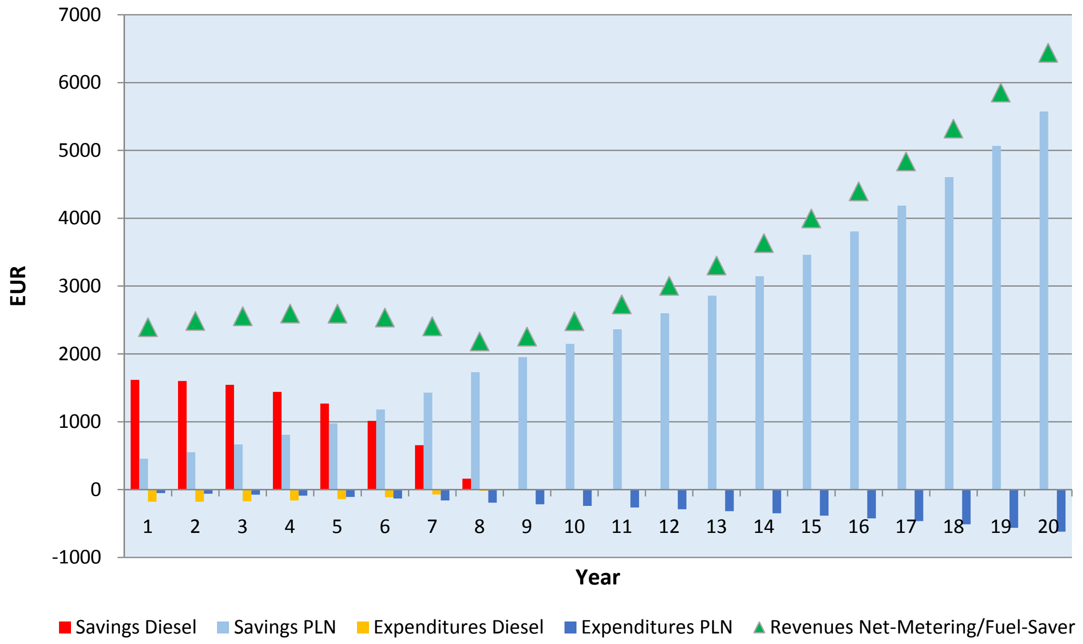

Figure 17: Expenditures / Savings for 50% ice making, 50% grid-availability and 10% GA increase

In the first year, the saved energy (50% grid-availability) and the resulting costs amount to 1600 EUR for diesel-fuel and 400 EUR for PLN electricity tariff. Besides these numbers, an additional revenue of 2400 EUR due to saved energy in case the ice machine is not operating. Additional expenses amount to 200 EUR for diesel fuel and 50 EUR for PLN electricity.

The initial grid-availability of 50% increases by 15% per year, resulting in decreasing diesel-fuel and increasing PLN tariff savings. In year 8 after the implementation, the grid-availability reached 100% and the system is only paid back using saved PLN electricity or net-metering revenues.

- For 100% PLN grid supply, only optimized (and well configured) systems are feasible as otherwise the payback period results in 17 years
- For 100% diesel-generator supply, the optimized 1 ton ice machines has a payback time of 7 years and an accumulated EBITA of 250.000 EUR after 20 years
- Solar driven ice machines are only feasible in areas with high (tending to 100%) diesel supply but allow for new ice production facilities to exploit new catch areas
- An initial low grid-availability can influence the project feasibility negatively even if slow grid-improvements (here: 5% per year) can be expected.
- Non daily ice production is a realistic case and influences the feasibility even in systems with high diesel fuel usage
- Diesel-fuel savers / net-metering options are essential to offset the loss emanating from unused electricity in case of non-continuous ice production

7. Conclusion

In this study, the economic potential of solar-driven ice machines was investigated. As most of Indonesian ice machines in remote areas in Indonesia are typically hand-made setups, energy efficiency measures are promising options as a basis for the implementation of renewable energies.

For the specific case, already small investments of 1000 EUR in energy saving measures can reduce the energy demand by 20% and payback periods of 2 years even under full on-grid operation. Larger investments for energy saving measures can contribute significantly to reduce the energy demand by up to 40%. In areas with high diesel fuel costs and frequent and long grid outages, an expected payback period of 6 years is demonstrated. For 100% on-grid operation, larger investments might not yet be attractive due to low electricity costs. In addition, optimization scenario can reduce the ice making time which enables the production to be shifted to daytime and thus increase the share of solar energy.

The economic feasibility for a 1 ton solar-driven ice machine was conducted based on a reference system of 20 kWp capacity equipped with a battery bank of 908 Ah and additional backup supply which is either provided by the grid or diesel generators. It was demonstrated that an investment of 40.000 EUR is feasible for one ton block ice per day, as long as an optimally-tuned ice machine setup is in place. Especially in remote areas with 100% diesel-supply, a payback of 6 years can be expected, assuming local diesel costs of 11.500 IDR/liter.

At the given location, grid-outages are common and 100% off-grid operation are not given. Thermally optimized ice machines can pay back after 9 years if a constant grid-outage of 12 hours per day during the project lifetime is assumed. Due to improvements in the electricity supply even small annual improvements (15% per year) affect the economic feasibility, and the payback period increase to 16 years. Besides the grid-availability, annual fluctuations in ice demand affect the economic feasibility. For the reference system where an annually continuous ice production is assumed, the calculations revealed a payback period of 7 years for 100% off-grid operation and 9 years for a grid-availability of 50%. In the case of 50% ice production over the year, the payback period increases to 12 years and 17 years respectively if the unused energy cannot be used for domestic energy supply (net-metering or diesel-fuel saver). If no daily ice production takes place but the energy produced is utilised domestically, the payback period would be the same as if daily ice production is given.

This study shows that solar-driven ice machines can be economically feasible in areas with high diesel-fuel usage with expected payback periods of around 7 years. For locations with high or even small increasing grid-availabilities, solar-driven ice machines are less feasible due to a highly subsidized electricity tariff. A non-continuous ice making due to seasonal fluctuations in fishing activities can be compensated if the excess energy produced by the PV system can be used domestically. Especially for remote areas, solar-driven ice machines are promising options to improve the value chain of fish and to exploit new catch areas.

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Solar Ice Making
Energy efficiency and Solar PV concepts

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