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IMPORTANT FACTORS WHEN CHOOSING INVERTERS FOR LARGE-SCALE PV SYSTEMS

Cost and yield comparison based on Fronius Eco 27.0-3-S

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Solar Energy

CONTENTS

1 INTRODUCTION

In order to make an informed decision on the right inverter for a PV system, it is not sufficient to consider the cost of the device alone. Instead, a decision should be made based on a detailed comparison of all costs incurred and the anticipated yields.

To do so, the CAPEX (capital expenditures) of the PV system – including costs influenced by the inverter – must first be considered.
The next logical step is to compare the anticipated OPEX (operational expenditures), so that a cost estimate for normal day-to-day operations can be created.
Finally, a precise analysis of the anticipated yields is essential, followed by an assessment of the inverter.

All of these factors will be investigated in this white paper. The Fronius Eco 27.0-3-S inverter will later be compared with other devices in order to highlight opportunities for short-term and long-term cost savings.

2 CAPEX ANALYSIS

The CAPEX (capital expenditures) will be analysed based on a comparison of the Fronius Eco 27.0 inverter with a 60-kW inverter from a competitor.

2.1 Description of the example system

Figure 1: Example system

The example system is a roof-mounted system with an output of 408 kWp, situated in central Europe and is used as the basis for the following study. A total of 13 Fronius Eco inverters or 6x 60-kW devices from another manufacturer are installed in the system.

Example system	
Installed PV generator	408 kWp
Total inverter output power	360 kVA
Number of Fronius Eco 27.0 inverters required	13
Number of 60-kW inverters required	6

Table 1: Overview of the example system

2.2 CAPEX

The CAPEX (*capital expenditures*) or CapEx refer to the investment costs of long-term assets[1]. These costs are important for determining the ROI (return on investment) or pay-back later down the line.
The cost structure of the example system is considered in the following comparisons. An in-depth breakdown of the costs (see table A1 above) can be found in the Appendix.

The CAPEX are broken down into individual sectors in the figure below.

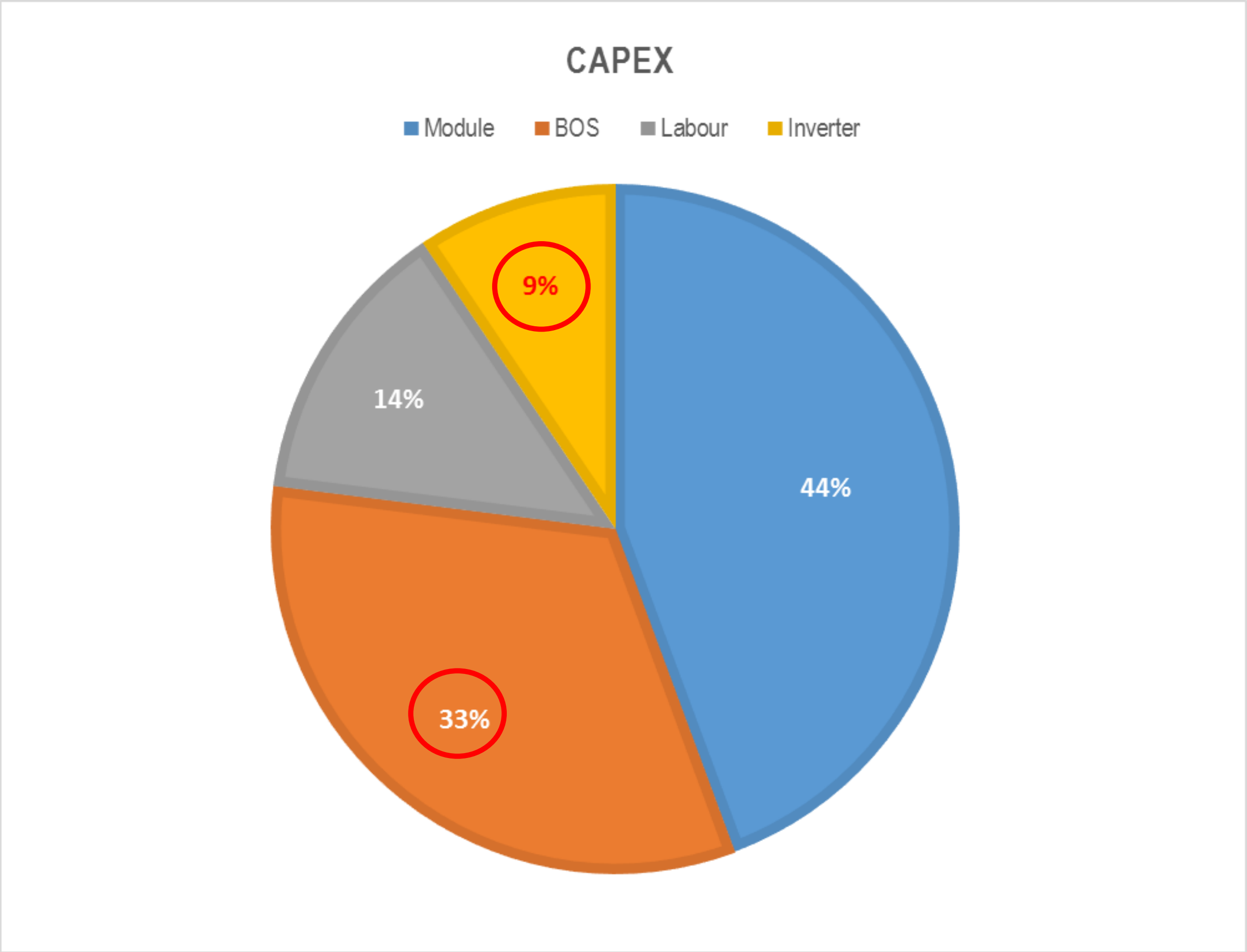

Figure 2: Overview of the CAPEX/initial system costs

As Figure 2 clearly illustrates, at 9%, the cost of purchasing the inverter only represents a very small proportion of the investment costs. However, this 9% has a big influence on the performance and therefore the yield of the PV system.

At one third, the BOS costs (33%) represent a much larger percentage of the total cost. The question here is how much influence intelligent system design has on these costs.

[1] http://wirtschaftslexikon.gabler.de/Definition/capex.html

2.3 BOS costs – Balance of system costs

BOS costs are all initial costs that are not related to the PV module or the inverter. They include the racking system, cable trays, AC and DC cabling, AC and DC distributor boxes and equipment for the main grid connection.

Together with the right system design, choosing the right inverter can produce huge savings. For this reason, a model cost calculation has been provided to compare the Fronius Eco 27.0 inverter and another 60-kW inverter in systems with a centralised design and those with a decentralised design.

The example system mentioned above has the following BOS cost breakdown.

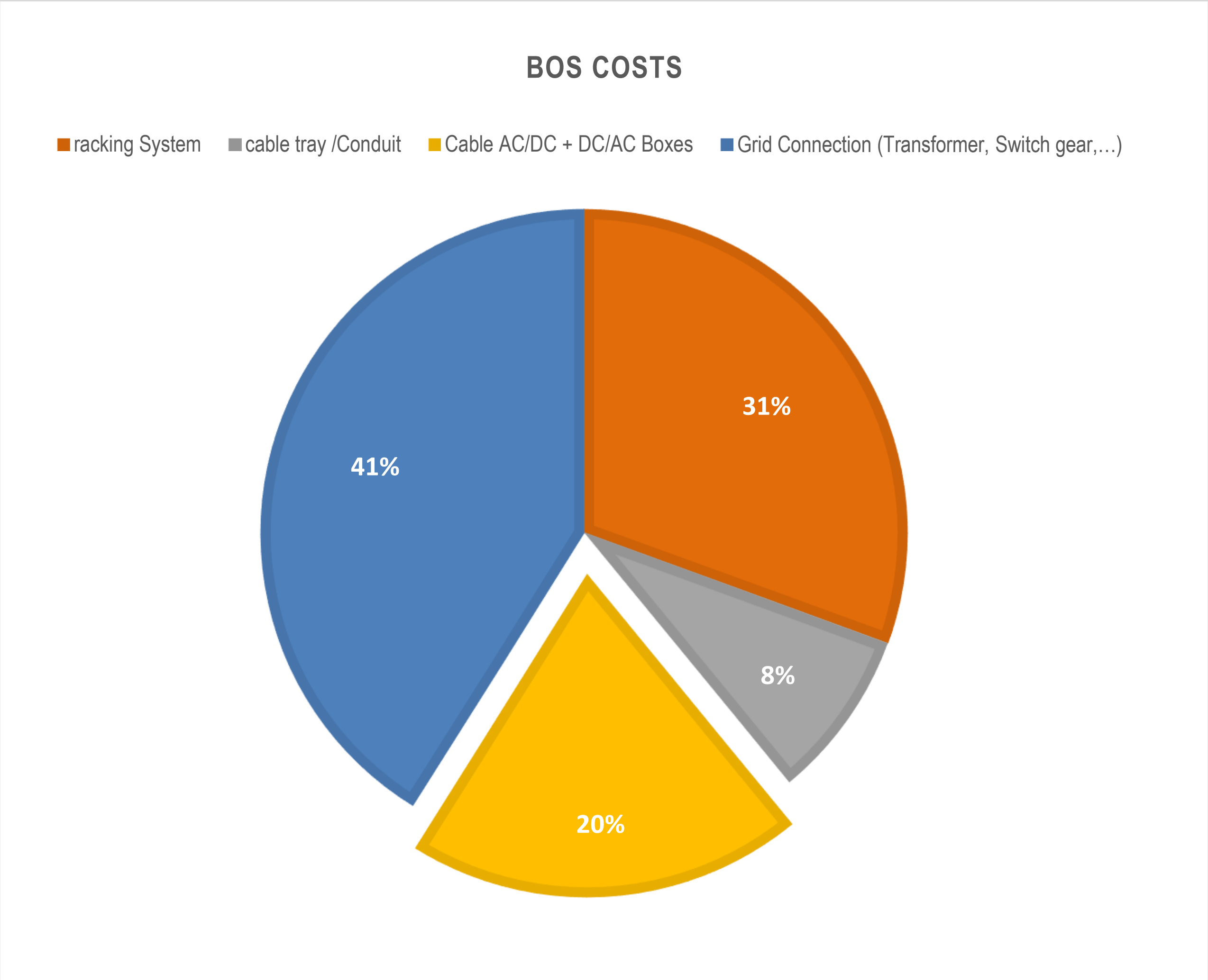

Figure 3: Overview of BOS costs breakdown (demo system)

Out of the various BOS costs shown above, the racking system (31%), cable trays (8%) and main grid connection (41%) are not affected by the choice of inverter. The inverter and system design have a considerable influence on the cost of AC/DC cabling + AC/DC distributor boxes (20%).

In order to highlight the precise cost correlations between these components, the difference between centralised and decentralised topology will be examined here. The main difference between these two types of system design is the type of cabling.

The dimensioning of the cable cross-sections in the study is based on a maximum voltage drop of 1% for both AC and DC sections.

For this reason, the 408 kWp roof-mounted system was used as an example. 13x Fronius Eco 27-kW and 6x 60-kW inverters were used.

2.3.1 Virtual centralised system design

In a system with a centralised design, the strings are first collected in a 'String Combiner Box' (SC) and just 2 cables connect to the inverter. Most of the distance between the PV modules and the inverter is covered using DC cables. The distance between the inverter and the AC distributor is, however, comparatively small.

Fronius Eco 27.0 with centralised system design

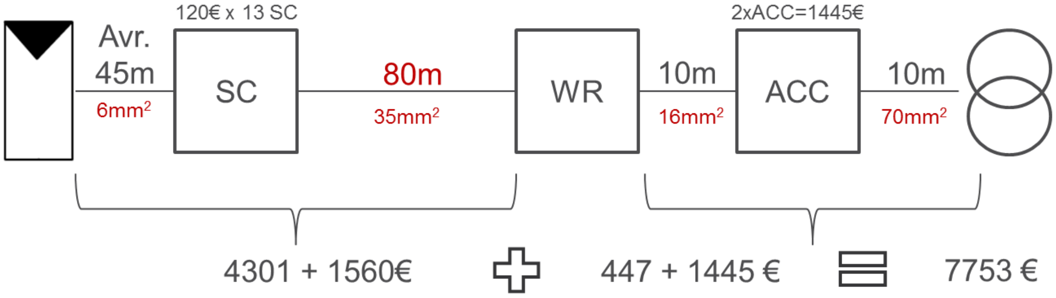

Figure 4: 350kVA - centralised system design with Fronius Eco

60-kW inverter with centralised system design

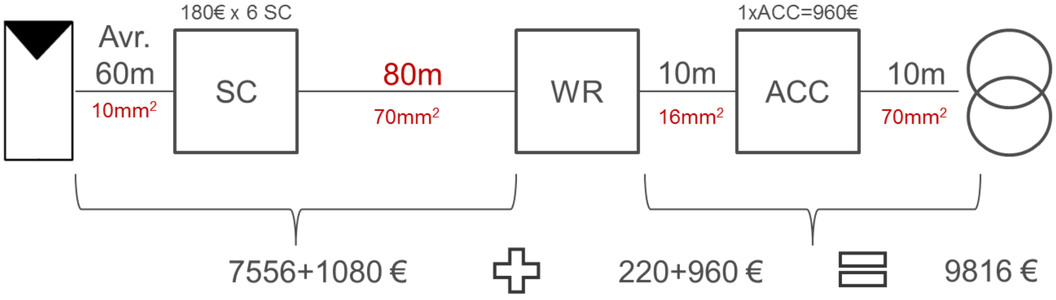

Figure 5: 350kVA - centralised system design with 60-kW inverter

As shown here, the difference in cost is mainly due to the different cable cross-sections as well as the costs of the distributor boxes.

2.3.2 Decentralised system design

In a system with a decentralised design, larger distances are covered using AC cables. Due to the distance, larger cable cross-sections are required in the AC section than in a system with a centralised design.

Fronius Eco 27.0 with decentralised system design

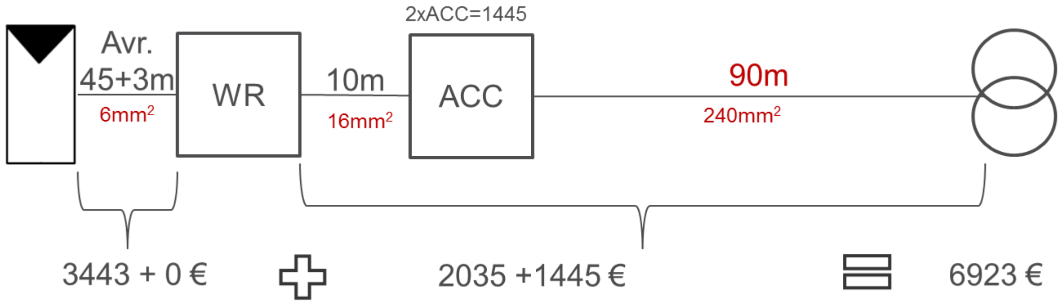

Figure 6: 350kVA - Decentralised system design with Fronius Eco

60-kW inverter with decentralised system design

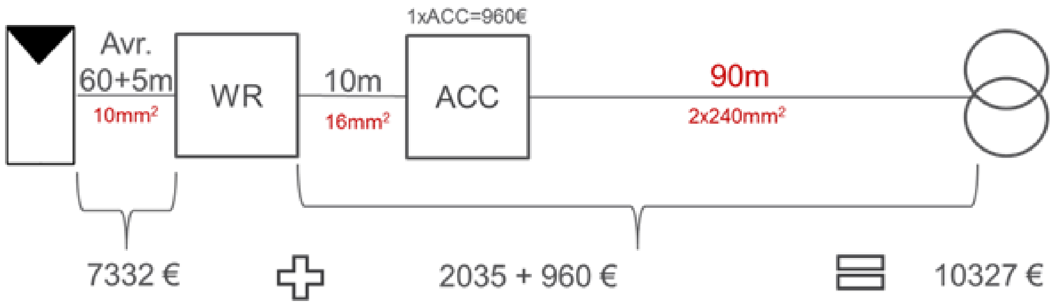

Figure 7: 350kVA - decentralised system design with 60-kW inverter

Here there is also a clear cost difference due to the different cable cross-sections and the AC distributor boxes (ACC).

In addition to the system design, the number of inverters and the number of connected AC fuses, AC distributors, DC boxes, over-voltage surge arresters and other components has an enormous influence on the BOS costs in certain circumstances.

2.3.3 BOS components

These influencing factors are listed in the following table. The table states the cost of BOS components for systems using the Fronius Eco 27.0 inverters or 60-kW inverters from another manufacturer.

Components	Fronius Eco 27.0	60-kW inverter
DC combiner box	€ 150	€ 220
AC distributor	€ 500	€ 350
AC overvoltage arrester	€ 50	€ 80
AC NH fuse	€ 3	€ 5
AC switch	€ 700	€ 1100

Table 2: Cost overview for AC/DC + distributor boxes

2.3.4 BOS overall costs

Depending on the distance between the PV module and the POI (Point of Interconnection), different cable cross-sections, the system design (centralised or decentralised), as well as the BOS components used, significant differences can be seen in the above prices with respect to the BOS of systems with Fronius Eco 27.0 inverters and systems with 60-kW inverters.

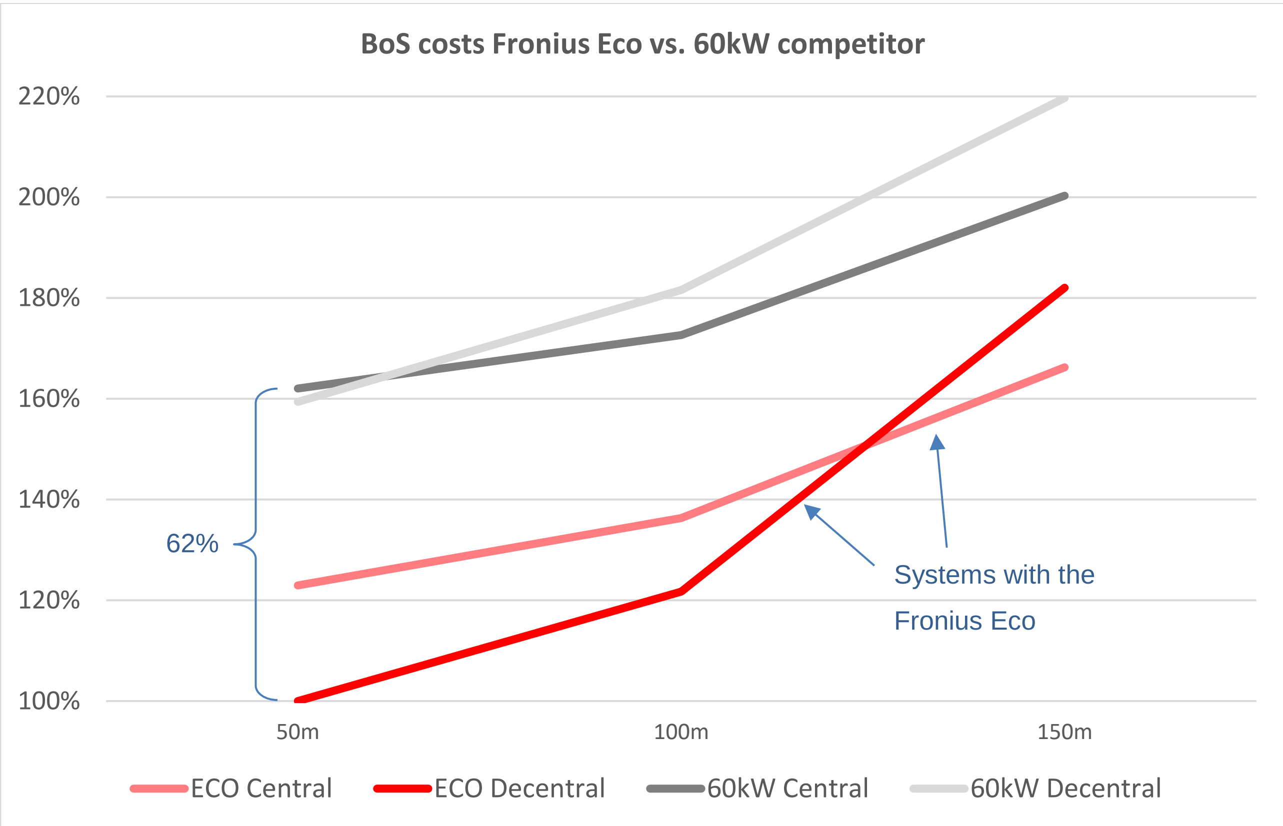

Figure 8: BOS cost comparison depending on cable lengths from modules to POI

As shown in the graph above, in the case of the 408 kWp/350 kVA example system, there is a cost benefit of up to **62%** for a system design using Fronius Eco devices.

This is made possible by the decentralised use of Fronius Eco devices and ensuring the distances between the modules and POI (Point of Interconnection) are as short as possible. Smart cost savings can be achieved in this area. The whole system was compared with another system using 60-kW inverters, a centralised system design and 100 m distance between the modules and the AC grid connection.

As the module mounting system, the cable trays and the equipment for the main grid connection are largely independent from the inverter, the difference in cost between the cables, AC and DC boxes is highlighted in the following comparison.

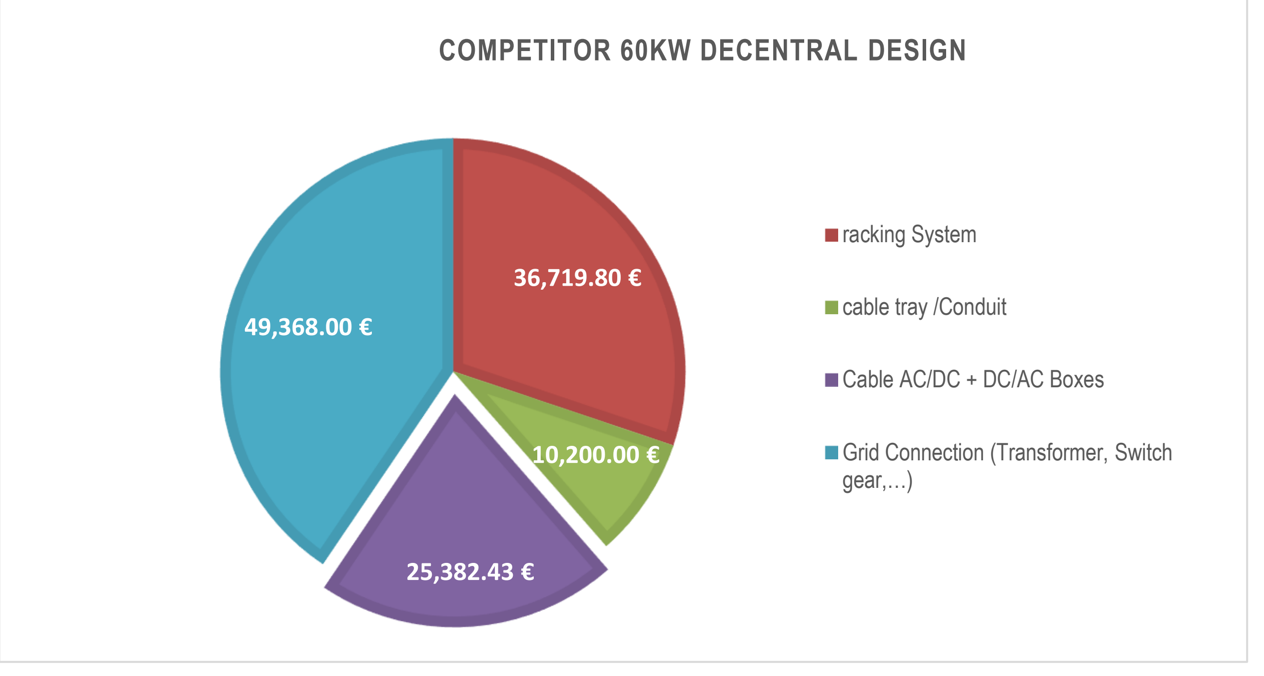

Figure 7: BOS costs for the 60-kW competitor inverter installation

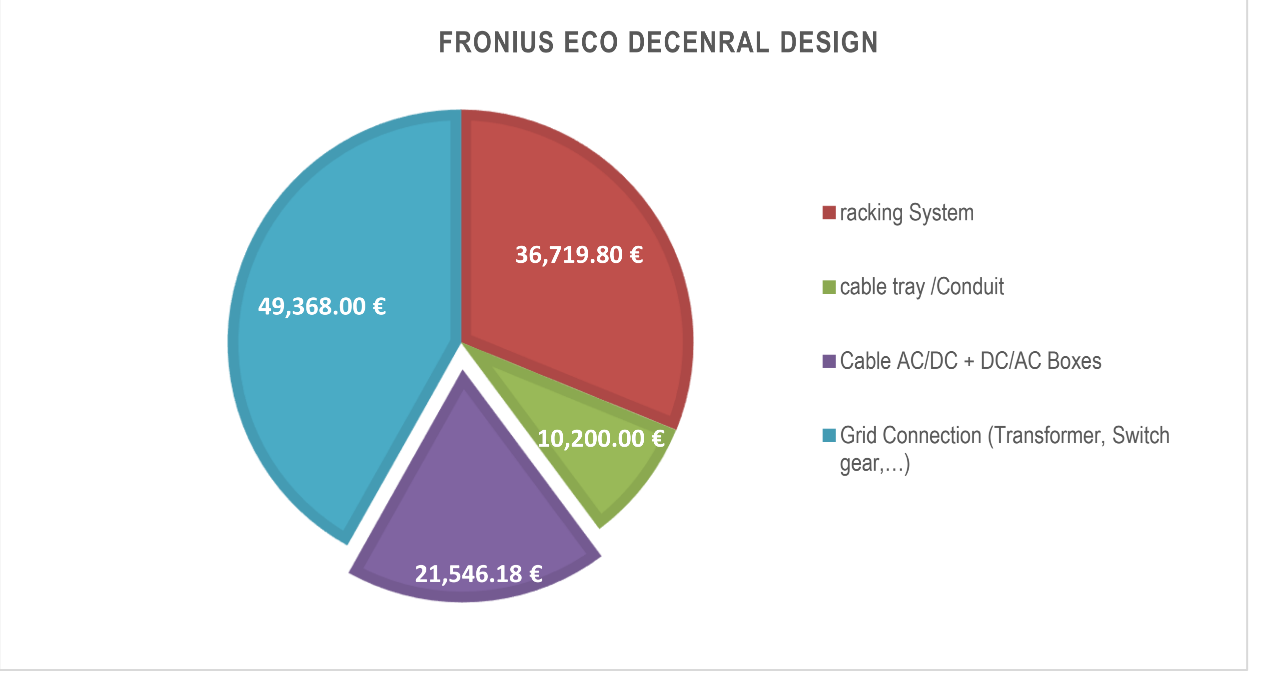

Figure 8: BOS costs for the Fronius Eco installation

2.4 Yield

Due to the different system voltages (AC 400 V, DC up to 1,000 V), cable lengths, and the resulting cable cross-sections, different levels of transmission loss occur. Depending on the project, this produces different results with respect to the yield of the system, which is examined more closely in Section 4.

3 OPEX ANALYSIS

In contrast to the investment costs for long-term assets (CAPEX), the OPEX (*operational expenditures*) refer to the ongoing costs for day-to-day commercial operations[2].

The OPEX consist of scheduled maintenance work and unplanned service callouts. Scheduled maintenance work is usually performed once per year and includes the following activities:

- Cleaning the PV modules
- Checking the cable connections
- U/I characteristic measurement
- Cleaning the cooling system of the inverter
- Thermography, if required

To perform an analysis of the annual OPEX, the actively cooled Fronius Eco 27.0 will be compared with a passively cooled device from another manufacturer.

		Site visits per year	Number of people	Duration [h]	Workload per year [h]	Hourly labour costs [€/h]	[€ per year]	[Total € per year]
Passively cooled device	Scheduled maintenance	2	1	10	20	€60	€ 1200	€ 1800
	Service callouts	0.5	2	10	10	€60	€ 600	
Fronius Eco 27 kW (actively cooled)	Scheduled maintenance	1	1	10	10	€60	€ 600	€ 720
	Service callouts	0.5	1	4	2	€60	€ 120	

Table 3: Overview of the annual costs for maintenance and service

The figures listed in the table are the result of various influencing factors:

- For a passively cooled inverter, the cooling fins must be cleaned more frequently than just once per year to prevent yield losses resulting from dust accumulation. (See also Figure A2 in the Appendix). For the Fronius Eco, which is actively cooled, this additional servicing cost does not apply. For this reason, double the servicing costs are included in the calculation for the passively cooled inverter.
- For unplanned service callouts, the calculation is based on 0.5 site visits per year for both products.
- The number of individuals required in the event of these callouts varies. If necessary, Fronius inverters can be serviced using the PC board replacement process, meaning that the entire inverter does not need to be replaced and one person can easily perform the servicing work on their own. In the case of string inverters for the commercial sector from other manufacturers, at least two people are required to replace the commercial inverter as it is too heavy to be handled by just one person. For this reason, when replacing inverters in large roof-mounted systems, a crane often needs to be

[2] http://wirtschaftslexikon.gabler.de/Definition/opex.html

made available as the device cannot be carried on narrow roof ladders. This requires more manpower, resulting in significantly higher costs.

- The Fronius Eco 27.0 shows a cost benefit of more than € 1,000 per year in comparison to the reference device (passively cooled).

4 ENERGY YIELD

A cost comparison of the CAPEX and OPEX is not on its own sufficient to determine the cost effectiveness of a system. The anticipated energy yield also represents a key factor and should be taken into account when selecting an inverter. This is used to determine the ROI or the LCOE (levelized costs of energy). The LCOE are calculated using: CAPEX + OPEX over a defined period of time divided by the energy yield (in kWh) over a defined period of time. The LCOE are usually given in c€/kWh.

In order to be able to draw yield comparisons, two inverters with as similar output power were chosen. In the next section, specific examples are used to compare the Fronius Eco 27.0-3-S (27-kW) with a passively cooled 33-kW competitor device.

4.1 ENERGY YIELD

Simulation software *PV Syst* was used for the comparison, which calculated the energy yields of both devices for the roof-mounted system referred to at the beginning.

Example system data	
Installed generator output	408 kWp
Installed AC output	350 kVA
PV modules	Canadian Solar CS6U-330M
Analysis tool used	PVsyst

Table 4: Key information on the example system

The performance is described as the annual yield per installed kWp of the system. As a result, the two different inverters have the following specific energy yields:

	Eco 27 kW (actively cooled)	**33 kW (passively cooled)**
Tinv = 10°C….45°C (0….1000W/m²)*	1273 kWh/KWp **(+4.17% yield increase)**	1222 kWh/kWp

Table 5: Result of a specific energy yield comparison in PVsyst3

When comparing the specific energy yield values, the Fronius Eco 27.0 generates an annual energy yield increase that is 4% higher than the 33-kW competitor device. Thus, the Fronius Eco achieves a specific energy yield of 1,273 kWh/kWp, while a 33 kW passively cooled device achieves a yield of 1,222 kWh/kWp. This difference is primarily a result of the different derating behaviour of the actively cooled Fronius device and the passively cooled 33-kW competitor device (details on the power derating behaviour

[3] PVsyst analysis (the temperature was determined over the course of a year based on the actual insolation values in Verona)

can be found in Figure A3 in the Appendix)

A detailed breakdown showing the energy yield in monetary terms is provided below. These calculations were based on the following data:

Annual energy yield for Fronius Eco acc. to PV .Syst	519,000 kWh[4]
Annual energy yield for 60kW competitor device acc. to PV Syst	497,300 kWh[5]
Feed-in tariff	7.9 ct./W[6]

Table 6: Data for energy yield calculation

The total and cumulative annual profit for the end customer is displayed below. Both the individual inverter costs and the servicing costs incurred annually are indicated under "costs".

Fronius Eco 27.0 with active cooling				
Years	Yield	Costs	Revenue	Cumulative revenue
1	€ 41,001.00	€ 720.00	€ 40,281.00	€ 40,281.00
2	€ 40,796.00	€ 720.00	€ 40,076.00	€ 80,357.00
3	€ 40,592.02	€ 720.00	€ 39,872.02	€ 120,229.02
4	€ 40,389.05	€ 720.00	€ 39,669.05	€ 159,898.07
5	€ 40,187.11	€ 720.00	€ 39,467.11	€ 199,365.18
6	€ 39,986.17	€ 720.00	€ 39,266.17	€ 238,631.35
7	€ 39,786.24	€ 720.00	€ 39,066.24	€ 277,697.59
8	€ 39,587.31	€ 720.00	€ 38,867.31	€ 316,564.90
9	€ 39,389.38	€ 720.00	€ 38,669.38	€ 355,234.28
10	€ 39,192.43	€ 720.00	€ 38,472.43	€ 393,706.71
11	€ 38,996.47	€ 720.00	€ 38,276.47	€ 431,983.18
12	€ 38,801.48	€ 720.00	€ 38,081.48	€ 470,064.66
13	€ 38,607.48	€ 720.00	€ 37,887.48	€ 507,952.14
14	€ 38,414.44	€ 720.00	€ 37,694.44	€ 545,646.58
15	€ 38,222.37	€ 720.00	€ 37,502.37	€ 583,148.95

Table 7: Total profit for end customers with the Fronius Eco 27.07

Passively cooled 33-kW competitor device				
Years	Yield	Costs	Revenue	Cumulative revenue
1	€ 39,289.83	€ 1,800.00 €	€ 37,489.83	€ 37,489.83
2	€ 39,093.38	€ 1,800.00 €	€ 37,293.38	€ 74,783.21
3	€ 38,897.91	€ 1,800.00 €	€ 37,097.91	€ 111,881.12
4	€ 38,703.42	€ 1,800.00 €	€ 36,903.42	€ 148,784.55
5	€ 38,509.91	€ 1,800.00 €	€ 36,709.91	€ 185,494.45
6	€ 38,317.36	€ 1,800.00 €	€ 36,517.36	€ 222,011.81
7	€ 38,125.77	€ 1,800.00 €	€ 36,325.77	€ 258,337.58
8	€ 37,935.14	€ 1,800.00 €	€ 36,135.14	€ 294,472.72
9	€ 37,745.47	€ 1,800.00 €	€ 35,945.47	€ 330,418.18
10	€ 37,556.74	€ 1,800.00 €	€ 35,756.74	€ 366,174.92

[4] Energy yield PV Syst analysis software for Central Europe/Northern Italy location
[5] Energy yield PV Syst analysis software for Central Europe/Northern Italy location
[6] Chosen due to the current 2017 OeMAG (Clearing and Settlement Agency for Green Electricity) tariff in Austria
[7] Fronius calculation (the annual energy yield has been reduced by 0.5% per year)

11	€ 37,368.95	€ 1,800.00 €	€ 35,568.95	€ 401,743.88
12	€ 37,182.11	€ 1,800.00	€ 35,382.11	€ 437,125.99
13	€ 36,996.20	€ 1,800.00	€ 35,196.20	€ 472,322.19
14	€ 36,811.22	€ 1,800.00	€ 35,011.22	€ 507,333.40
15	€ 36,627.16	€ 1,800.00	€ 34,827.16	€ 542,160.57

Table 8: Total profit for end customers' yields from the 33-kW device

Compared with the reference device (passively cooled), the Fronius Eco 27.0 offers a cost benefit of more than € 1,000 per year. This means that the cumulative OPEX costs for the Fronius device are approximately € 10,800, whereas the costs for the competitor device can be assumed to be € 27,000. A difference of € 16,200!

In addition, the following graph clearly shows a yield benefit for the Fronius Eco due to the differences in performance and derating behaviour.

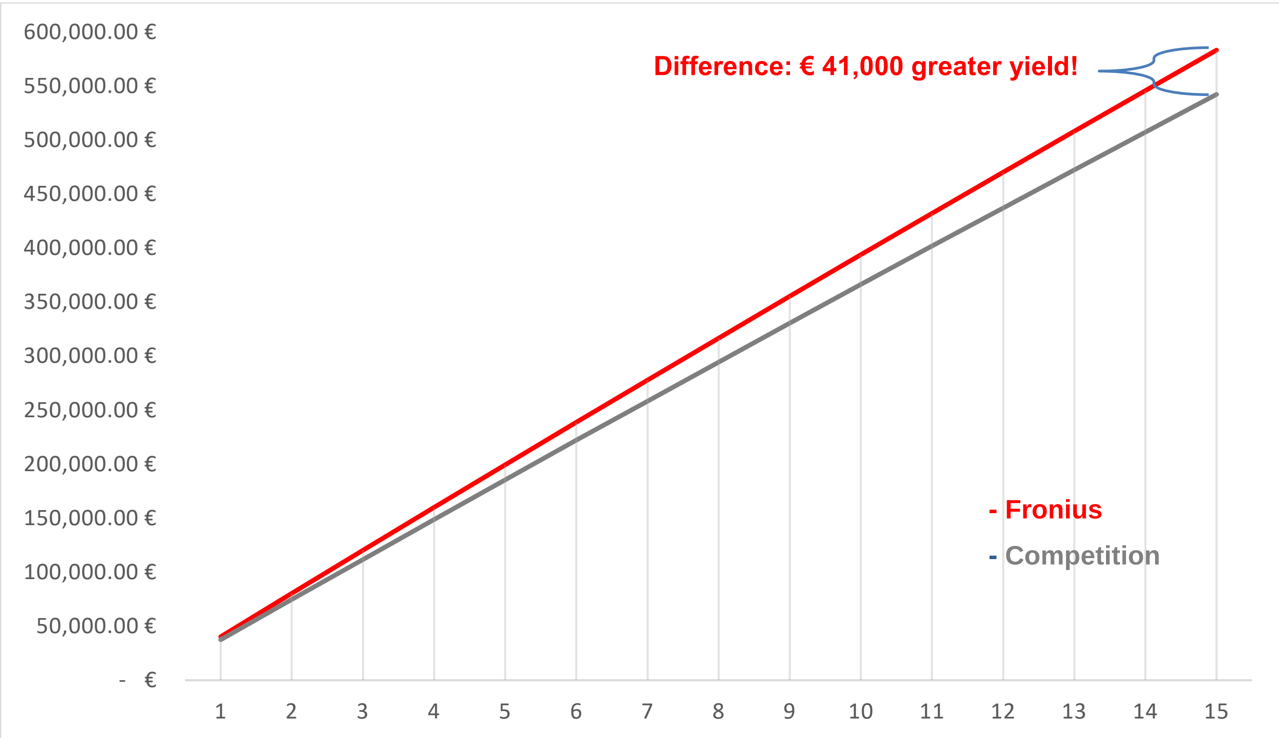

Figure 9: Total profit trend over 15 years

Calculated over 15 years, the Fronius Eco 27.0 generates a cumulative profit of € 41,000 in comparison to the competitor device.

5 SUMMARY

This analysis aims to explain the different key factors and uses model calculations to show that choosing the right inverter has a long-term impact on costs, yields and subsequently on the ROI of a PV system.
The model calculations have revealed the following:

Both the power category of the inverter and the system design have a significant influence on the BOS. The comparison showed that a decentralised Fronius Eco 27.0 with a shorter distance from the modules to the AC grid connection is the most cost-effective solution. Compared to solutions using a 60-kW competitor device, a **cost saving** of up to **62%** in a sub-area of the BOS costs could be achieved.

The choice of inverter determines the servicing costs incurred throughout the total operating time and thus the OPEX. Factors such as active or passive cooling or the PC board replacement process from Fronius, which provides for particularly efficient and affordable servicing, are the reason behind the results of the calculation: compared with the reference device (passively cooled), the Fronius Eco 27.0 offers a cost benefit of over € 1,000 per year.

Combined with the energy yield calculated for the Fronius Eco 27.0 and 33-kW reference device using the PVsyst simulation software, the calculations show that over 15 years, the Fronius Eco 27.0 generates a **total profit** for the end customer that is **€41,000** higher than that generated from the 33-kW competitor device.

Overall, it can be concluded that performing an analysis of all costs and yields for the Fronius Eco 27.0 demonstrates a clear cost saving. Considering the purchasing costs for the inverter alone does not give an accurate picture of the costs and profitability of a PV system.

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6 APPENDIX

6.1 Detailed CAPEX for example system

	€/Wp	[Wp]			
System size rooftop		**408,000**			
PV-Module	0.400 €	163,200.00 €	**Module**	**163,200.00 €**	**44.4%**
racking System	0.090 €	36,719.80 €			
cable tray /Conduit	0.025 €	10,200.00 €	**BOS**		
Cable AC/DC + DC/AC Boxes	0.058 €	23,832.75 €			
Grid Connection (Transformer, Switch gear,...)	0.121 €	49,368.00 €		**120,120.55 €**	**32.6%**
Assembly DC-Connection (Modul, Cable, Racking	0.090 €	36,720.00 €			
Assembly AC-Connection (Cable, AC Panel,...)	0.020 €	8,160.00 €			
Assembly Inverter	- €	- €	**Labour**		
Engineering	0.010 €	4,080.00 €			
Projectmanagement	0.003 €	1,020.00 €		**49,980.00 €**	**13.6%**
Inverter	0.080 €	32,640.00 €	**Inverter**		
Monitoring system	0.005 €	2,040.00 €		**34,680.00 €**	**9.4%**
Risiko Buffer	0.030 €	12,240.00 €			
Total	0.93 €	**380,220.55 €**			

Table A1: CAPEX for example system

The cost calculation is based on a 1.6 MW system constructed in Austria in 2017.

6.2 Extract from Operating Instructions for the reference device for calculating the OPEX

Routine Maintenance Checklist

Check Item	Check Method	Maintenance Interval
System cleaning	Check periodically that the heat sink is free from dust and blockage. Turn off the DC switch and then turn it on at night to clean the oxide off the switch.	6 months to annually.
System running status	Check that the SUN2000 is not damaged or deformed. Check for normal sound emitted during operation of the SUN2000. Check that all SUN2000 parameter settings are correctly set during operation.	6 months
Electrical Connections	Check that cables are securely connected. Check that cables are intact and the parts in contact with a metallic surface are not scratched. Check that the idle RS485 and USB ports are covered by waterproof caps.	6 months
Grounding reliability	Check that PGND cables are securely connected.	6 months

Figure A2: Operating Instructions for the 33-kW competitor device (extract)

6.3 Comparison of power derating behaviour

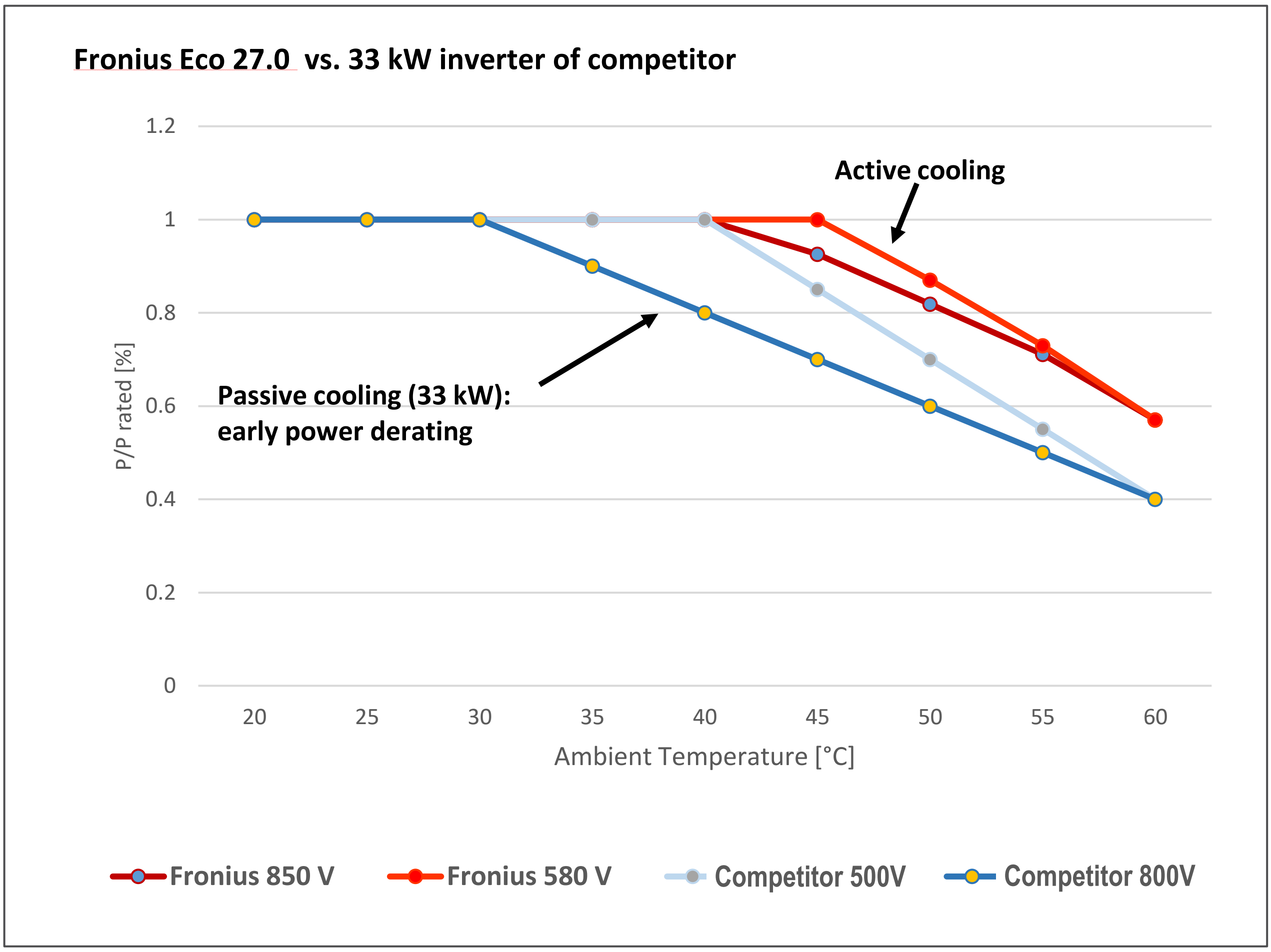

Figure A3: Derating behaviour of actively and passively cooled devices

Source: Competitor