Introduction

Chargers:

1) Costs and what influence them
2) Indirect charging costs

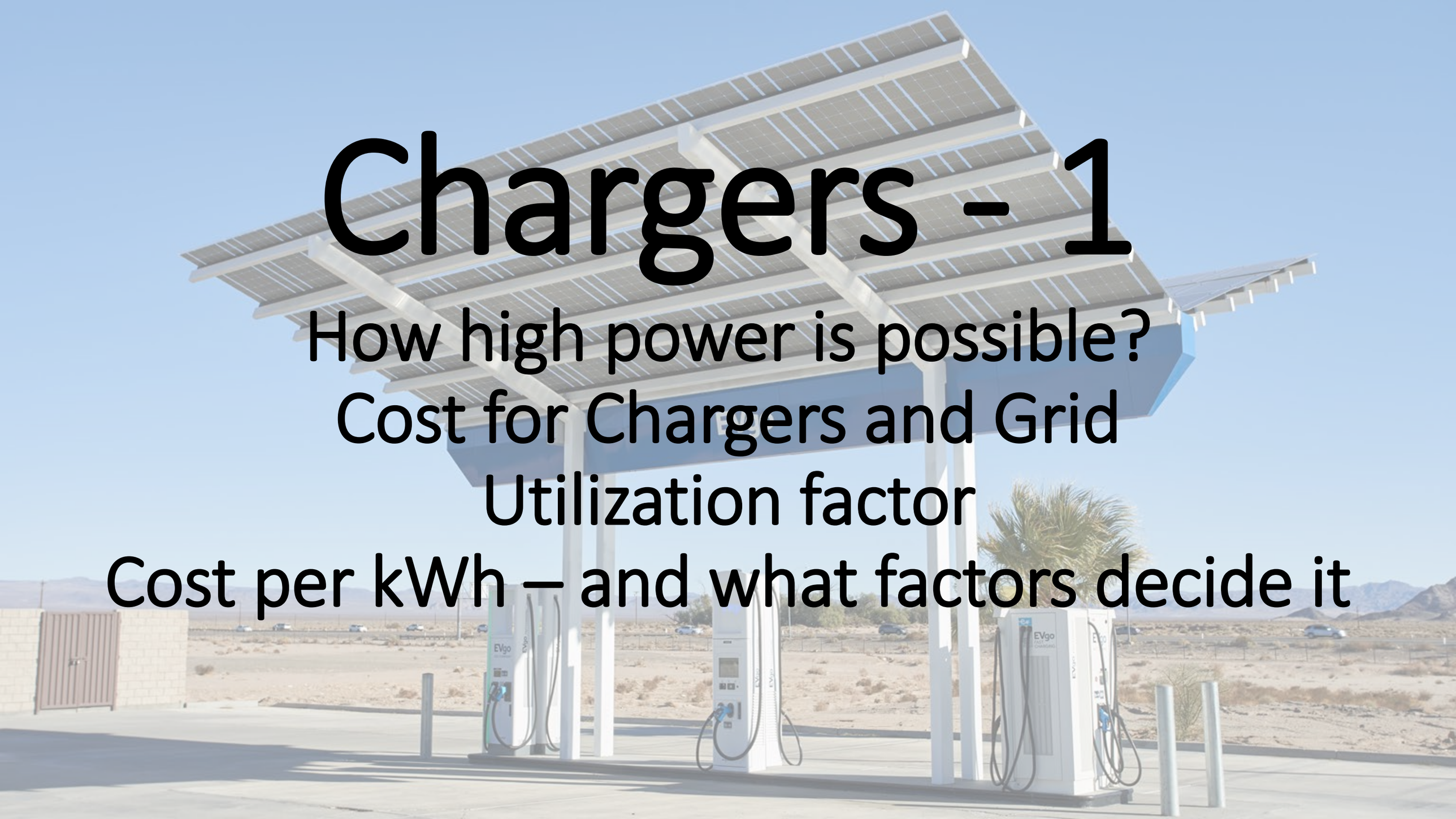
    Which charger power? Selecting charger.

Trucks:

3) Vehicle use, Battery utilization, Vehicle TCO
4) How to get high battery utilization

    Fast charging rarely/every day

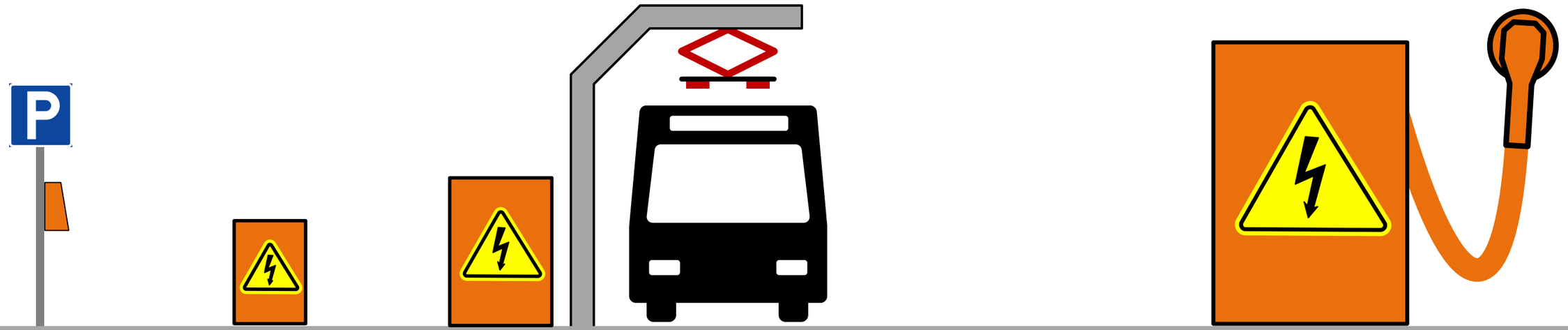
Summary + What is still unclear



Chargers - 1

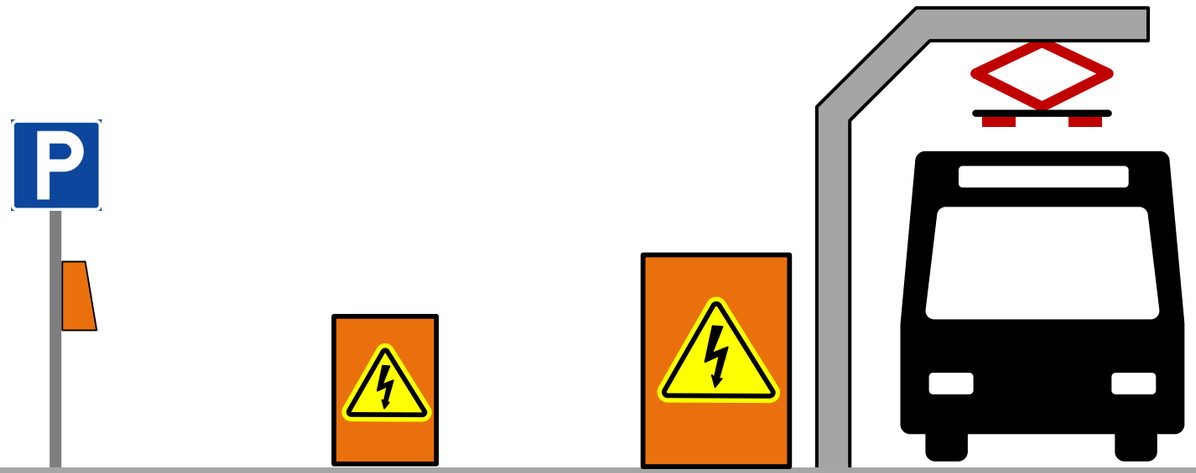
How high power is possible?
Cost for Chargers and Grid
Utilization factor
Cost per kWh – and what factors decide it

How big Chargers?



2 kW 150 kW 750 kW 10’000 kW

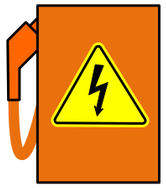
How big Chargers?



7 kW 150 kW 750 kW 1’000 - 3’000 kW

Cost for Chargers and Grid

Cost for chargers

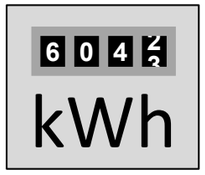


Purchase Charger 300 €/kW 7 yr

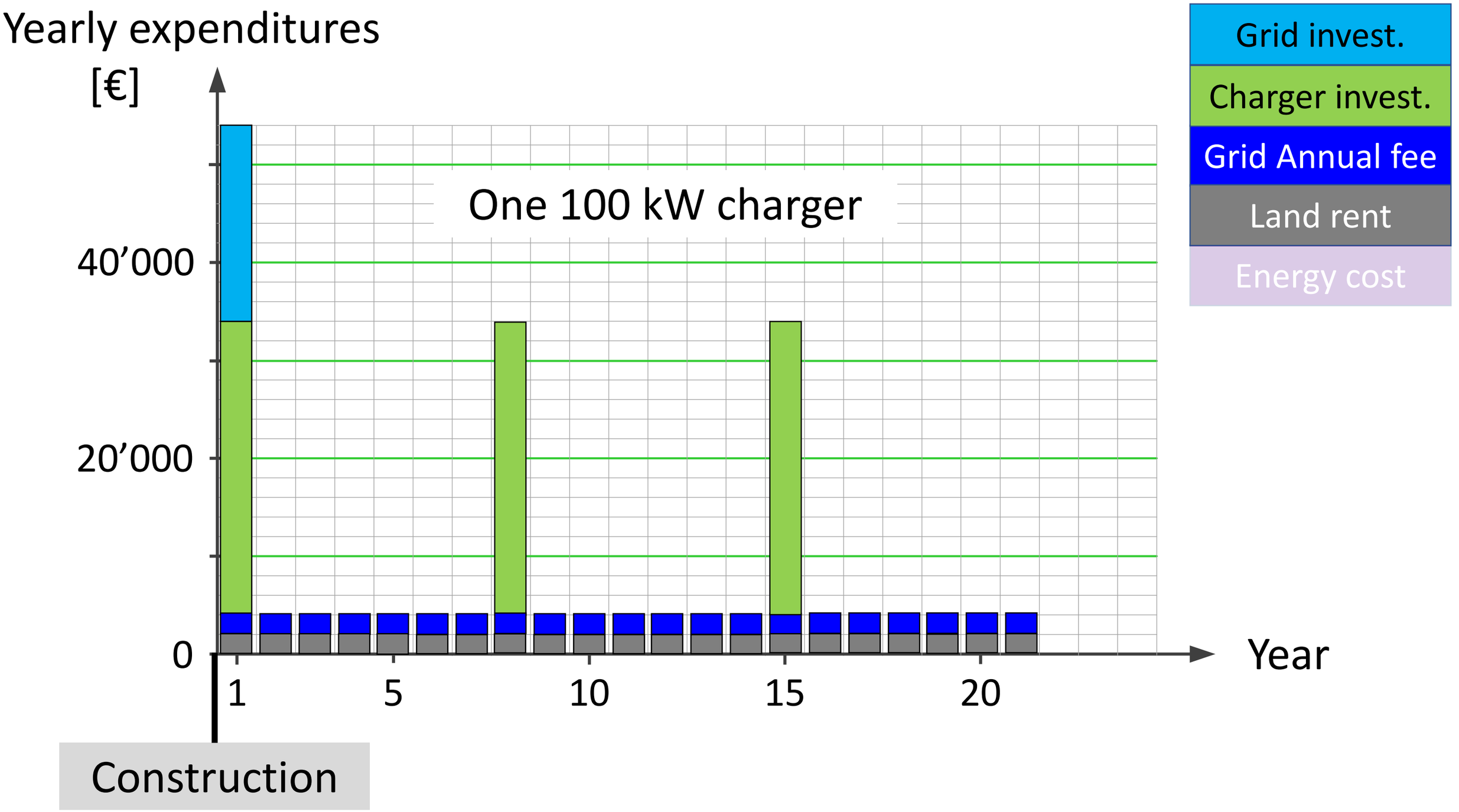
Grid connection cost 200 €/kW 21 yr

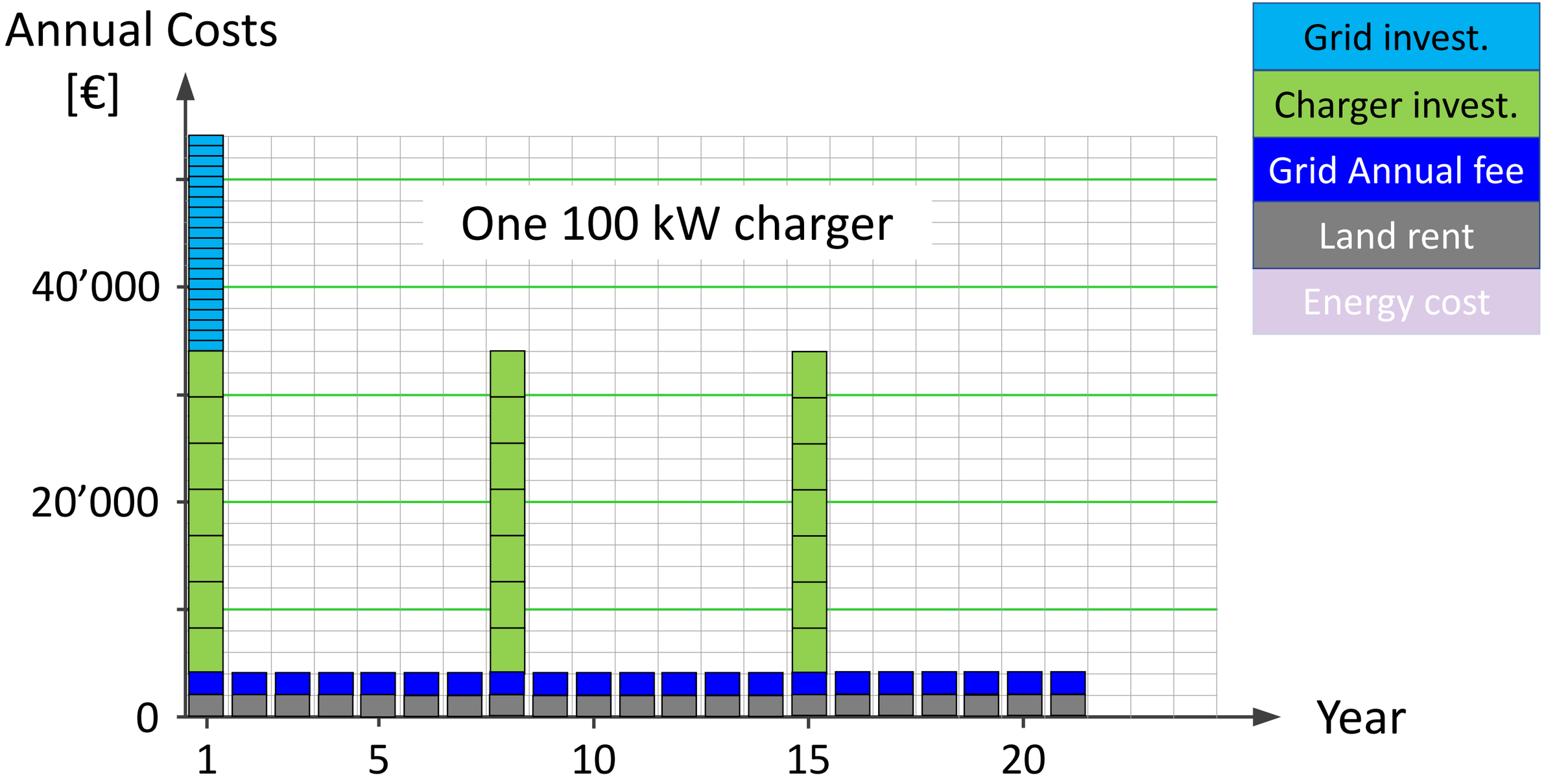
Annual grid subscription fee 20 €/kW/yr

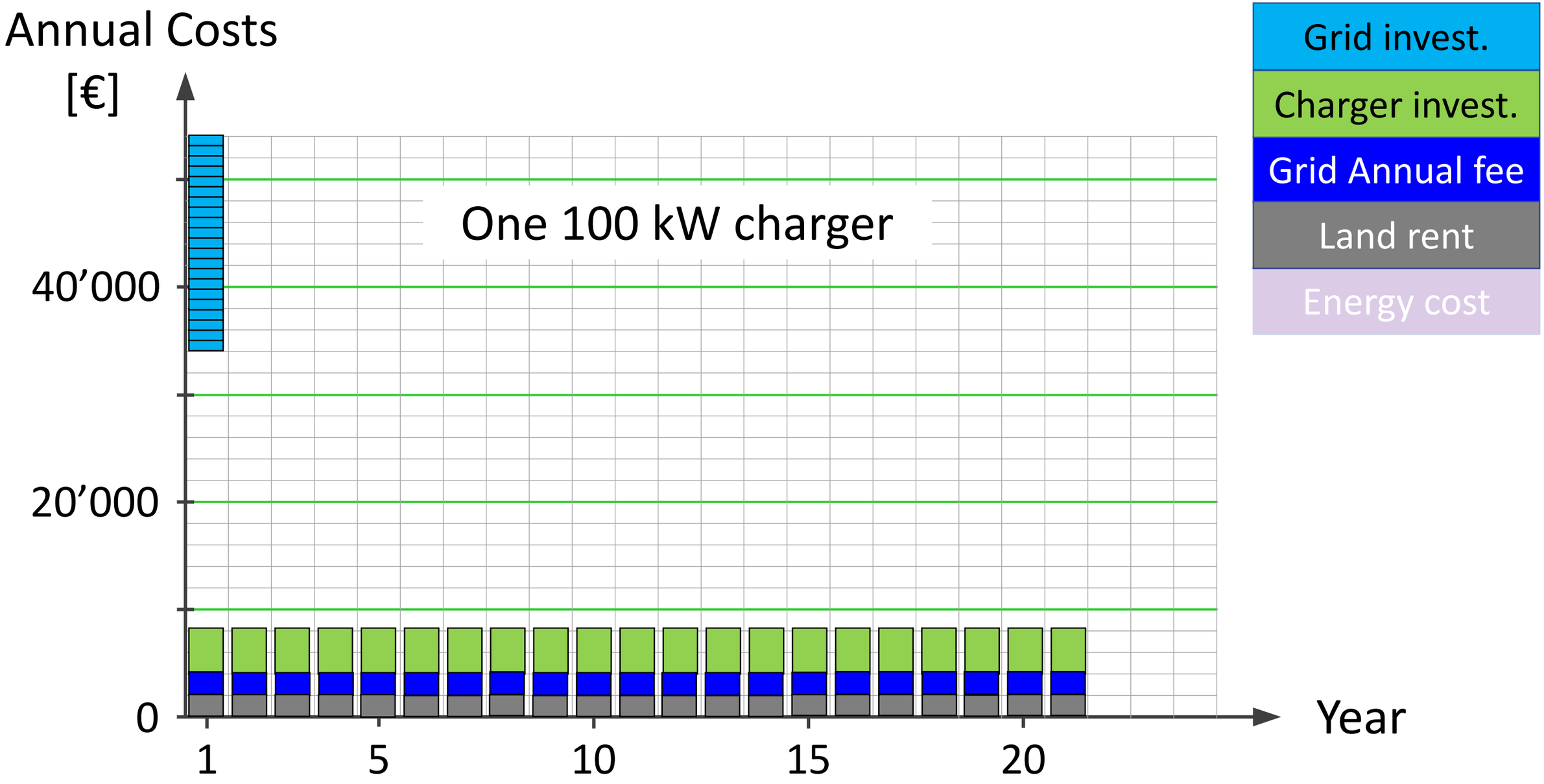
Annual rent for land 2000 €/yr

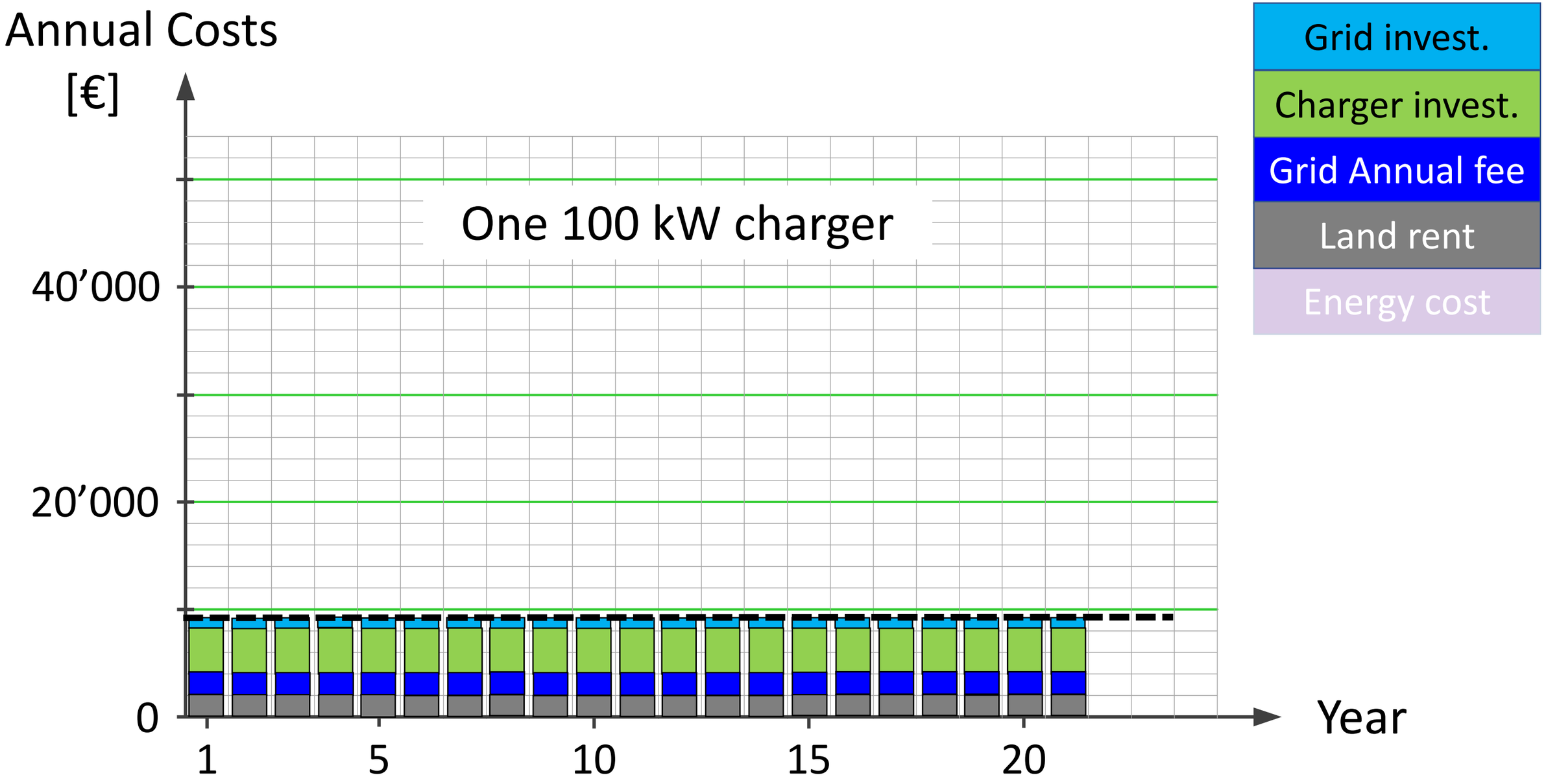


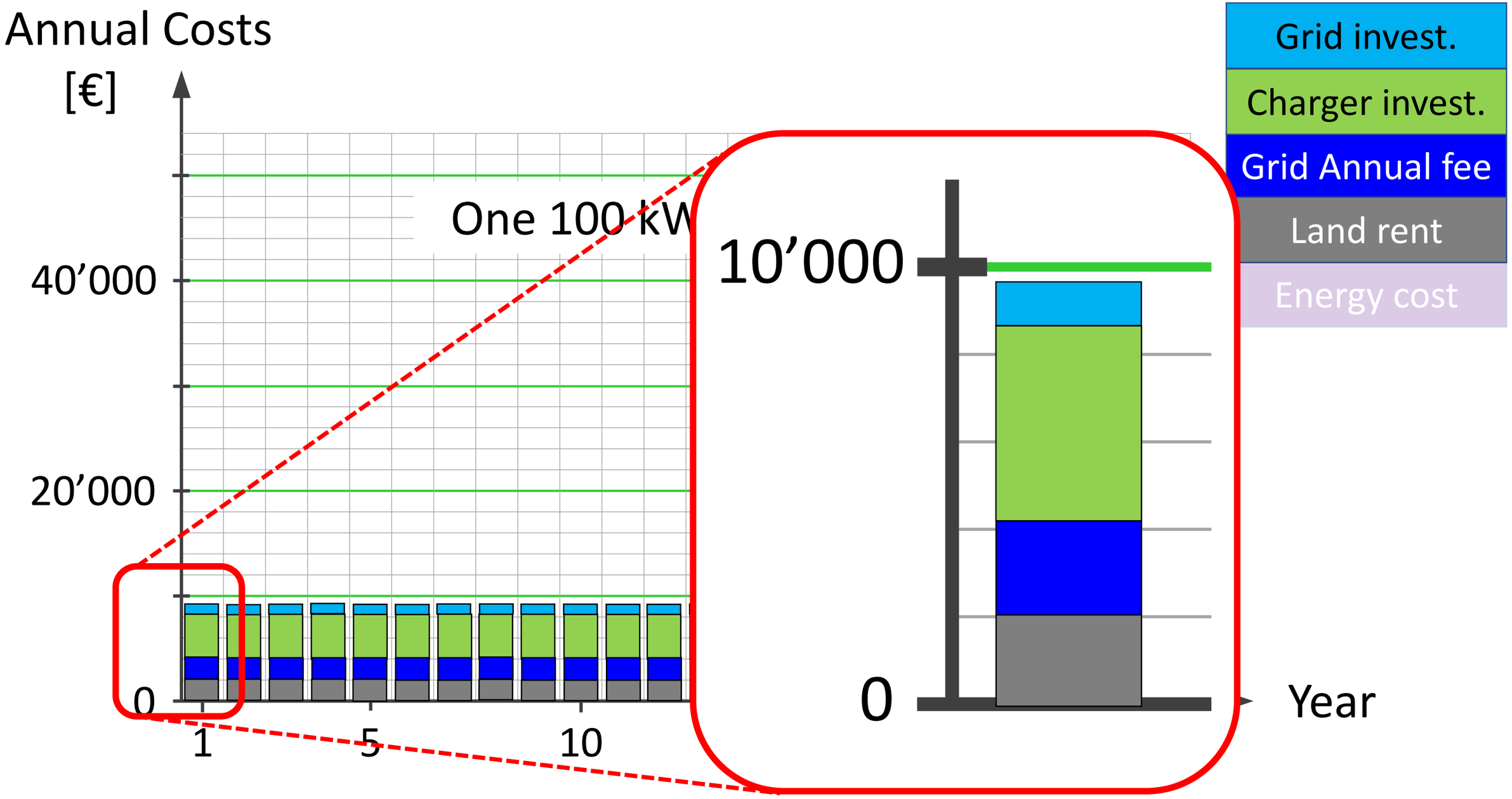
Energy cost 0.1 €/kWh


Yearly expenditures
[€]
40’000
20’000
0
One 100 kW charger
1
5
10
15
20
Year
Construction
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Annual Costs
[€]
One 100 kW charger
40’000
20’000
0
1
5
10
15
20
Year
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Annual Costs
[€]
One 100 kW charger
40’000
20’000
0
1
5
10
15
20
Year
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Annual Costs
[€]
One 100 kW charger
40’000
20’000
0
1
5
10
15
20
Year
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Annual Costs
[€]
40’000
20’000
0
1
5
10
One 100 kW
10’000
0
Year
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

Charger utilization and Annual Energy

$$\text{Charger Utilization} = \frac{\text{Energy charged in a year}}{\text{Charger Power} \times 8760\ \text{h/yr}}$$

(0-100%)

8 h/night @ full power — Utilization = 33 %

- Exclude weekends = 24 %

- Average @50% of full power = 12 %

1 h/weekday @ full power = 3 %

$$\text{Charger Utilization} = \frac{\text{Average Power}}{\text{Charger Power}}$$

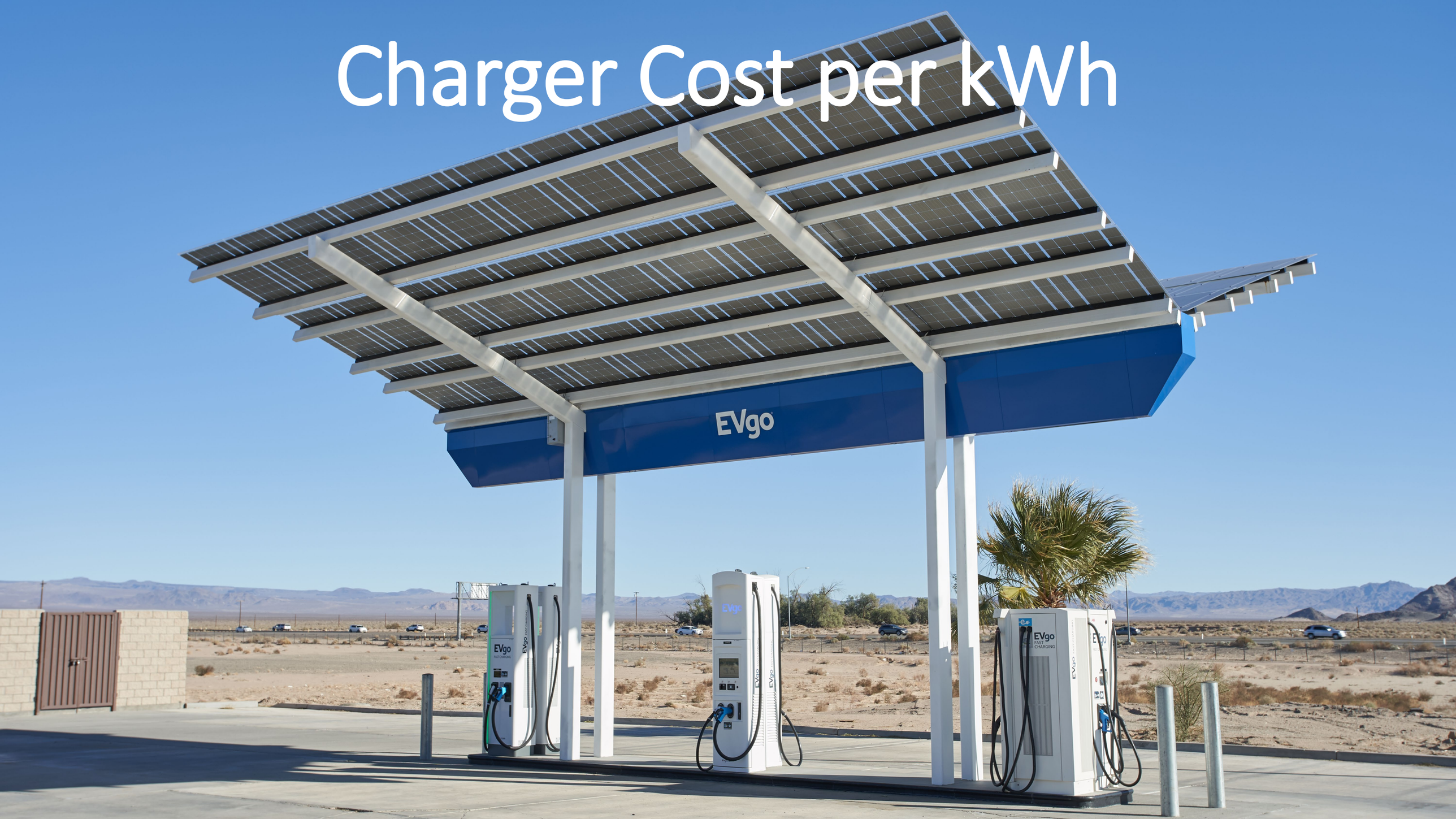
(0-100%)

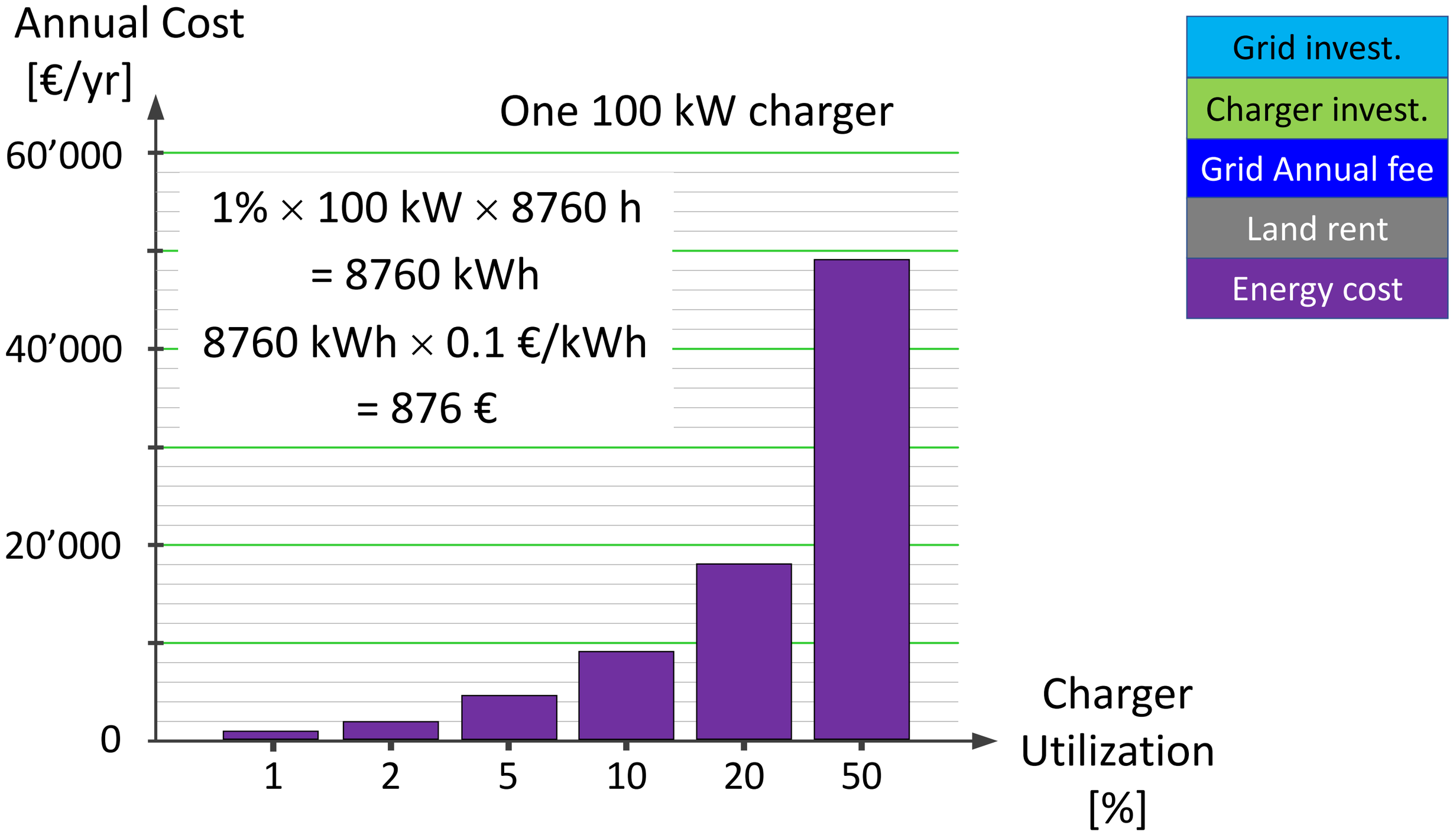
8 h/night @ full power — Utilization = 33 %

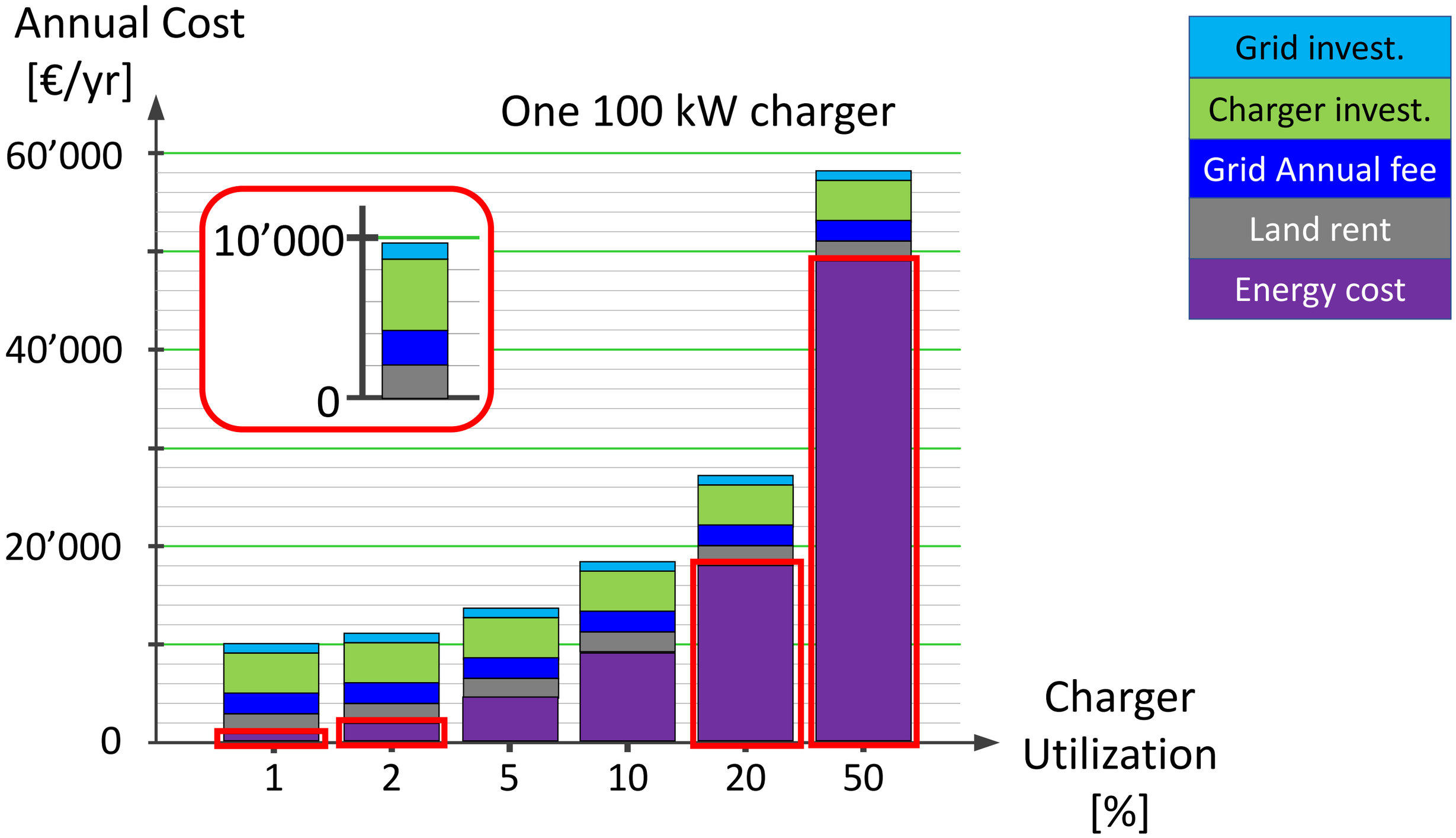
- Exclude weekends = 24 %
- Average @50% of full power = 12 %

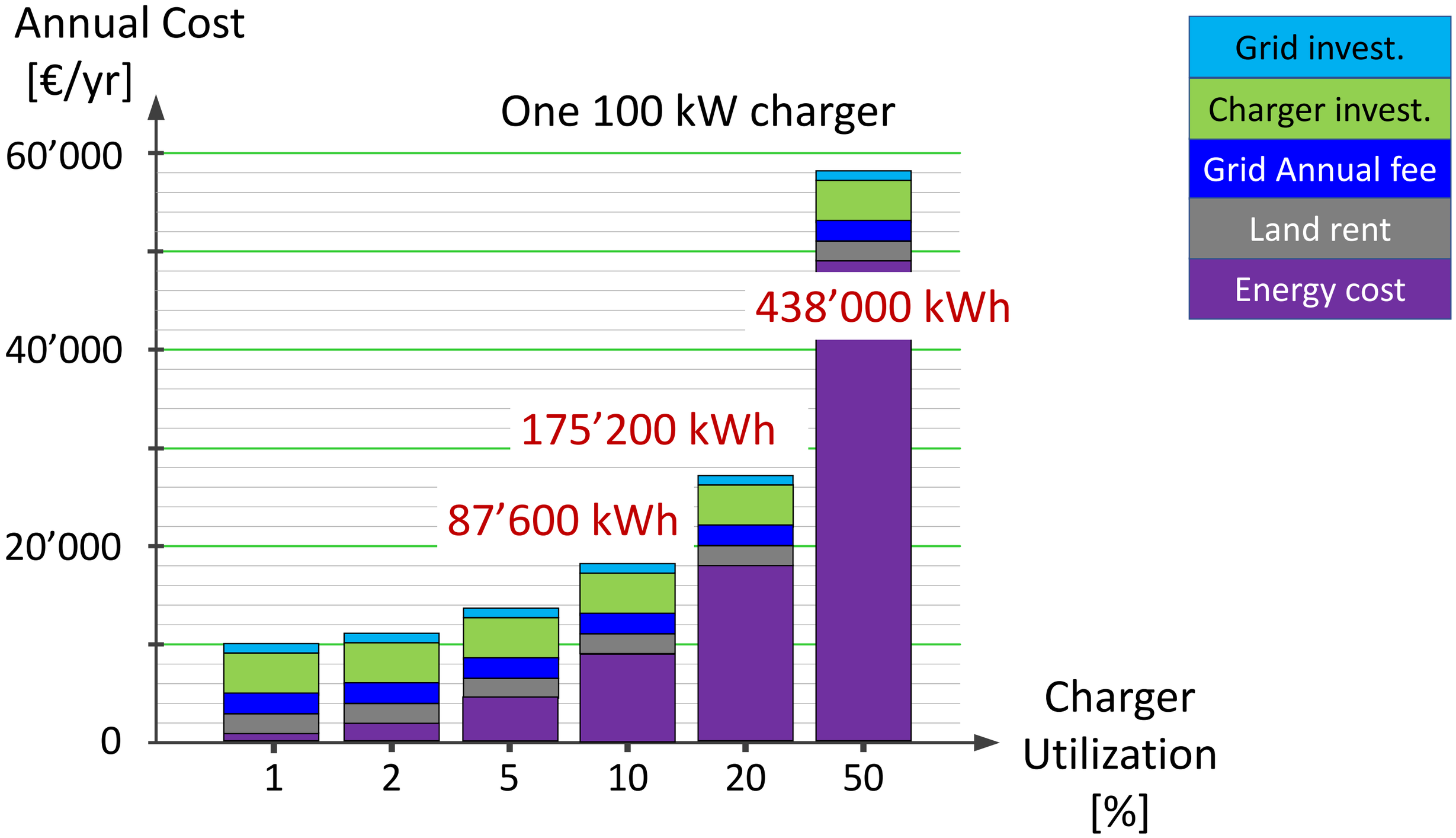
1 h/weekday @ full power = 3 %

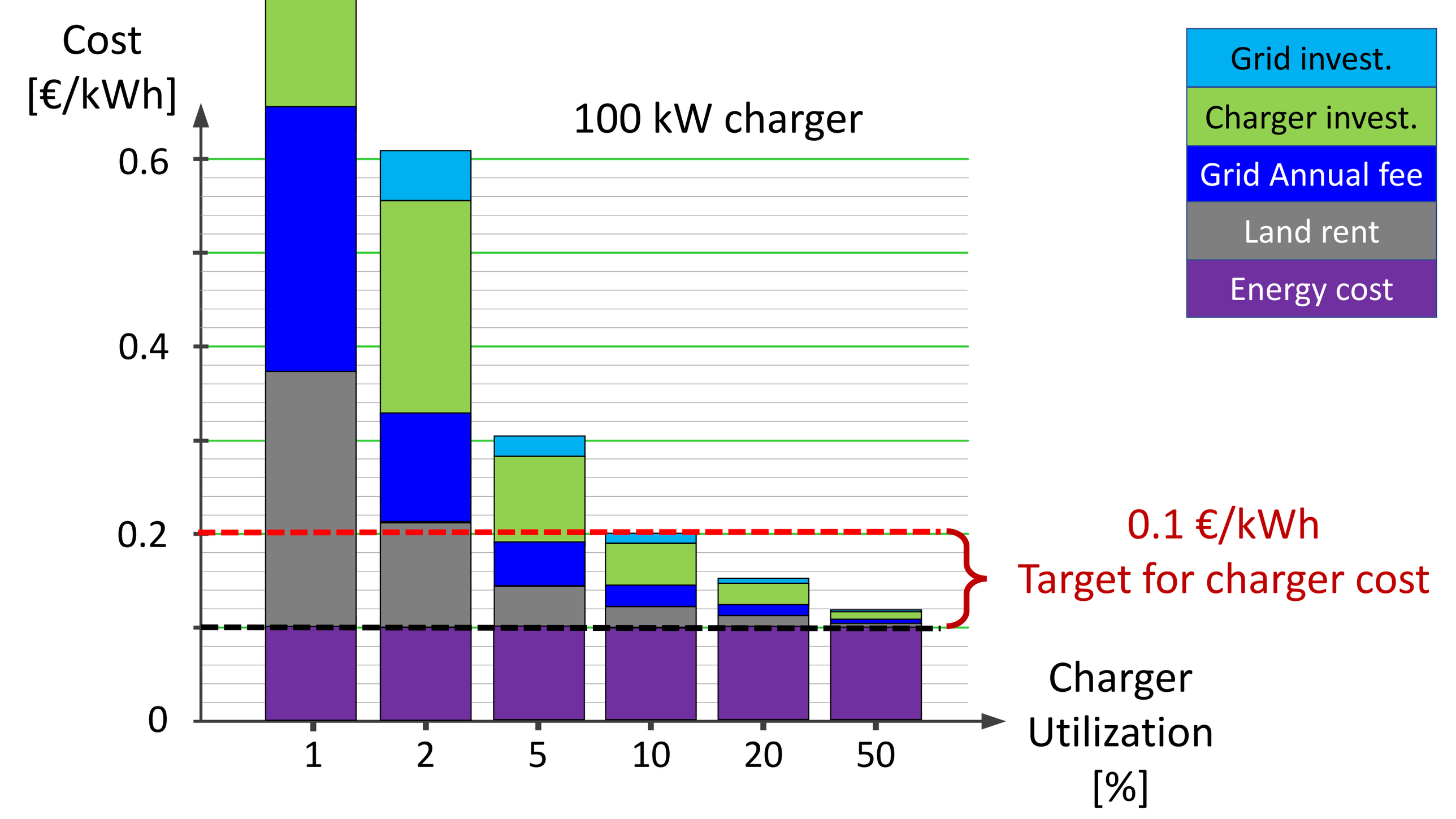
Charger Cost per kWh

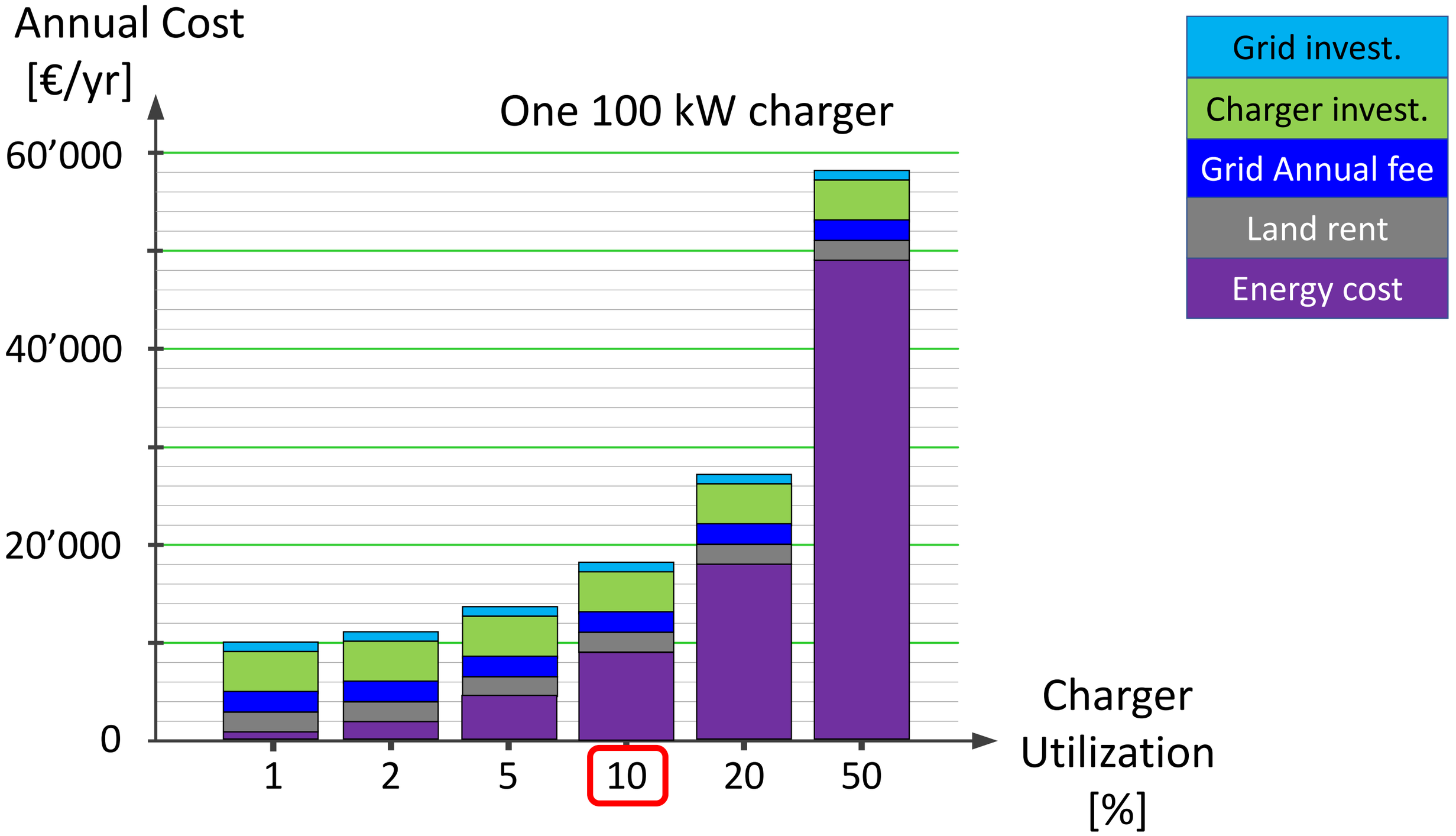


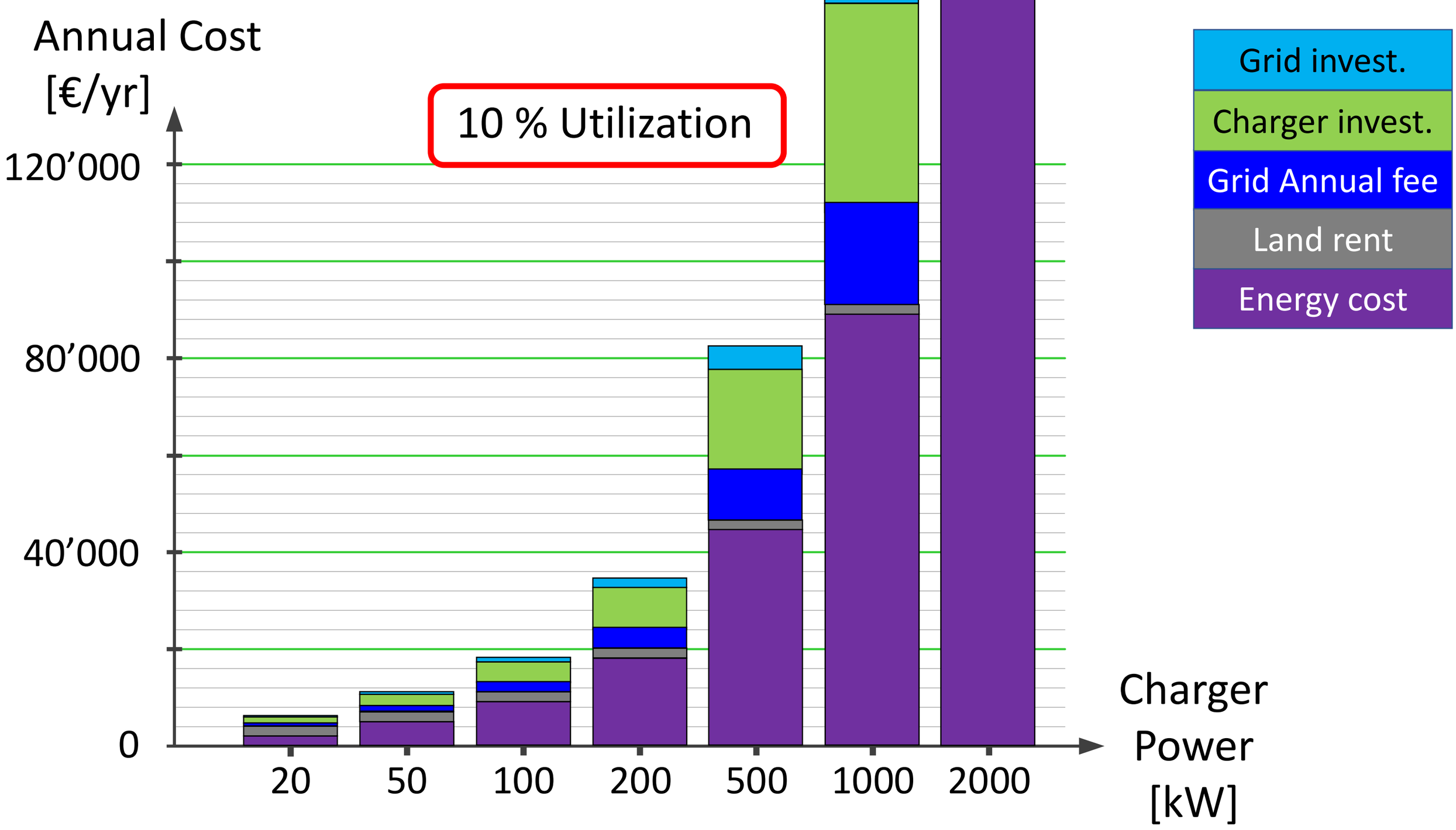

Annual Cost
[€/yr]
One 100 kW charger
60’000
40’000
20’000
0
1% × 100 kW × 8760 h
= 8760 kWh
8760 kWh × 0.1 €/kWh
= 876 €
1
2
5
10
20
50
Charger
Utilization
[%]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

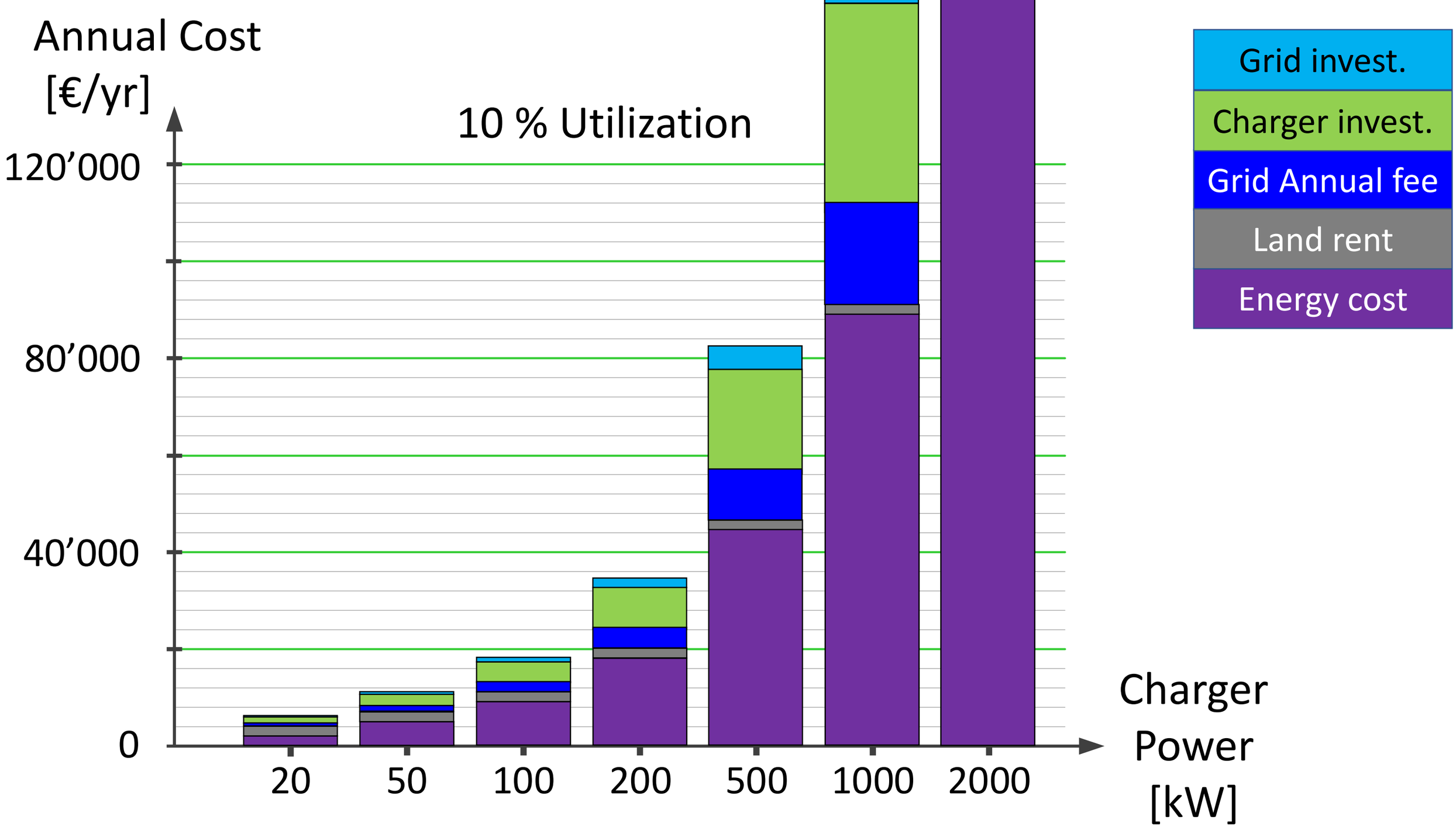

Annual Cost
[€/yr]
One 100 kW charger
60’000
40’000
20’000
0
10’000
0
1
2
5
10
20
50
Charger
Utilization
[%]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

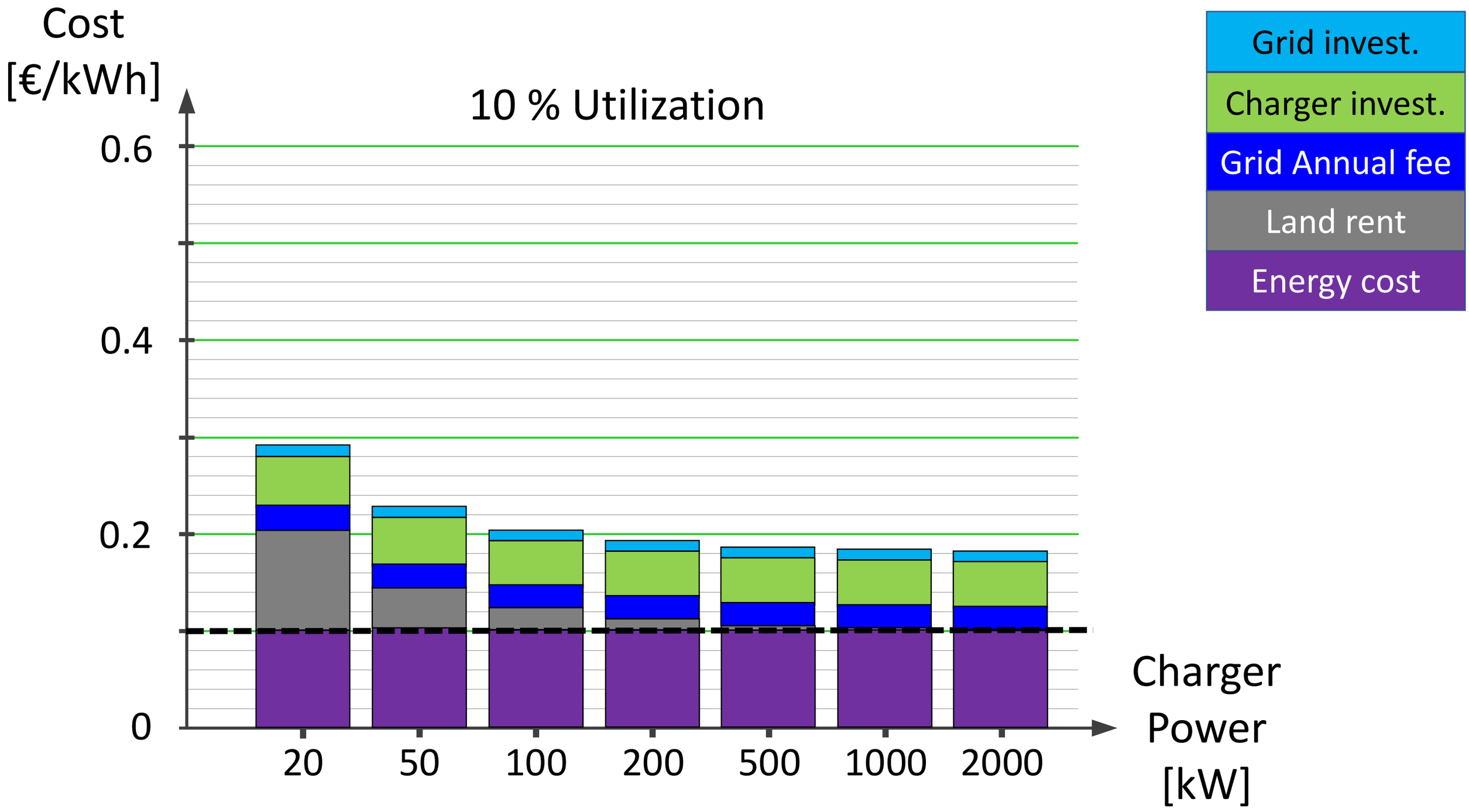

Annual Cost
[€/yr]
One 100 kW charger
60’000
40’000
20’000
0
438’000 kWh
175’200 kWh
87’600 kWh
1
2
5
10
20
50
Charger
Utilization
[%]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

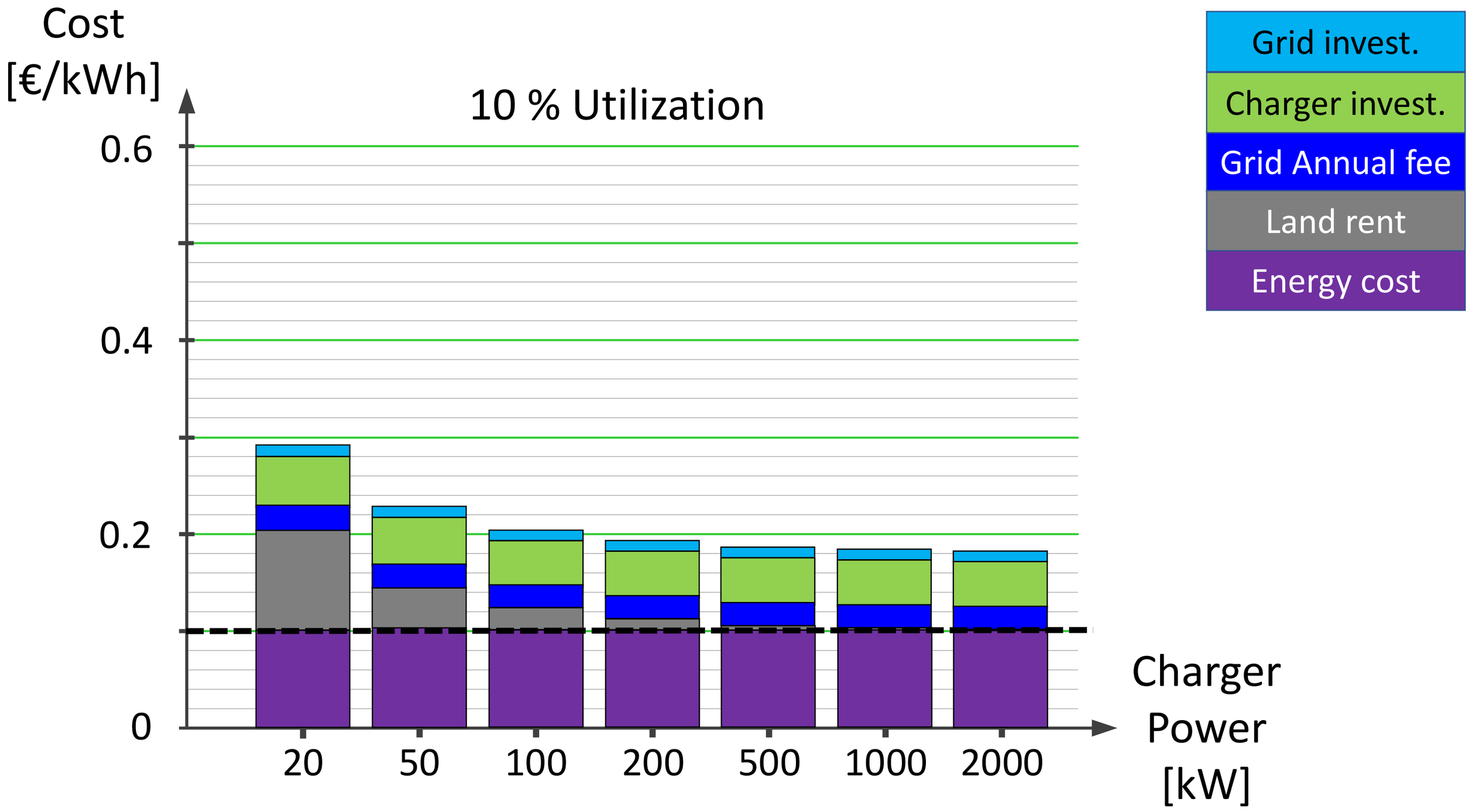

Cost
[€/kWh]
100 kW charger
0.6
0.4
0.2
0
1
2
5
10
20
50
Charger
Utilization
[%]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost
0.1 €/kWh
Target for charger cost

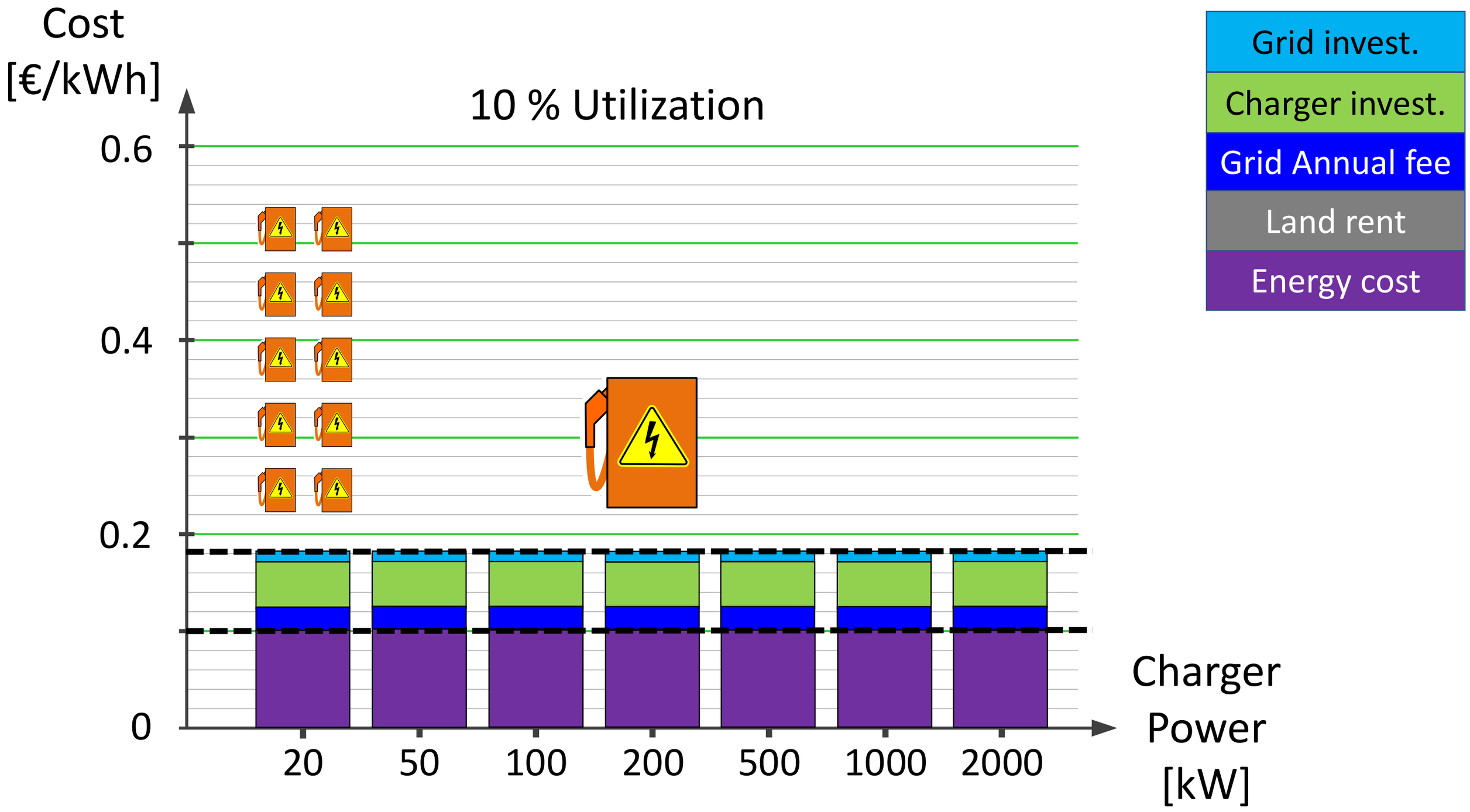

Annual Cost
[€/yr]
One 100 kW charger
60’000
40’000
20’000
0
1
2
5
10
20
50
Charger
Utilization
[%]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Annual Cost
[€/yr]
10 % Utilization
120’000
80’000
40’000
0
20
50
100
200
500
1000
2000
Charger
Power
[kW]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Annual Cost
[€/yr]
10 % Utilization
120’000
80’000
40’000
0
20
50
100
200
500
1000
2000
Charger
Power
[kW]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

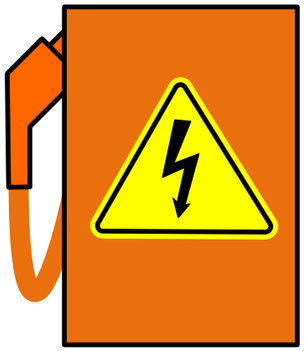

Cost
[€/kWh]
10 % Utilization
0.6
0.4
0.2
0
20
50
100
200
500
1000
2000
Charger
Power
[kW]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Cost
[€/kWh]
10 % Utilization
0.6
0.4
0.2
0
20
50
100
200
500
1000
2000
Charger
Power
[kW]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

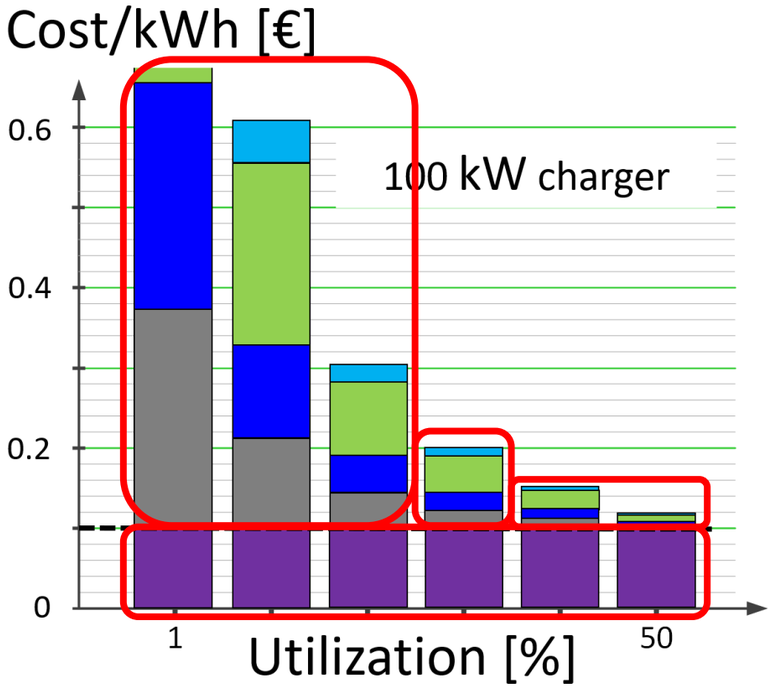

Cost
[€/kWh]
10 % Utilization
0.6
0.4
0.2
0
20
50
100
200
500
1000
2000
Charger
Power
[kW]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

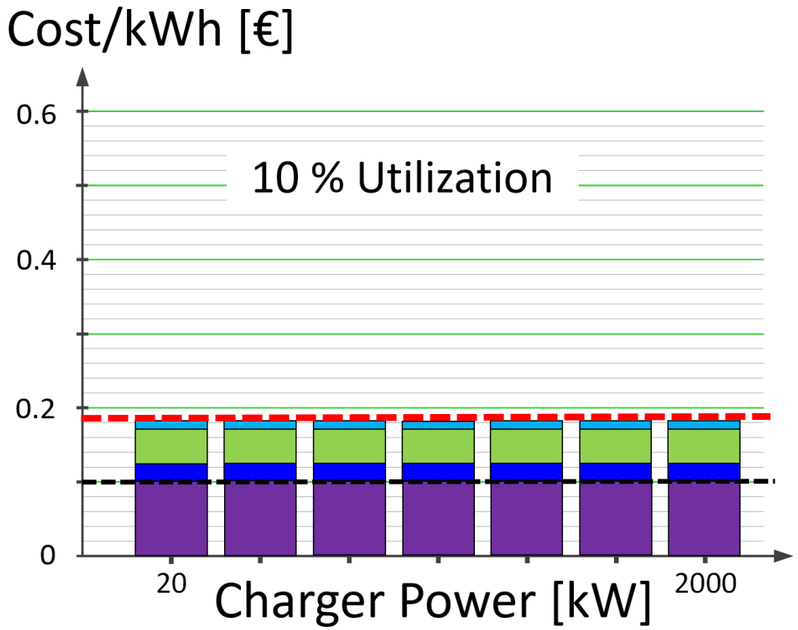
Charger cost per kWh

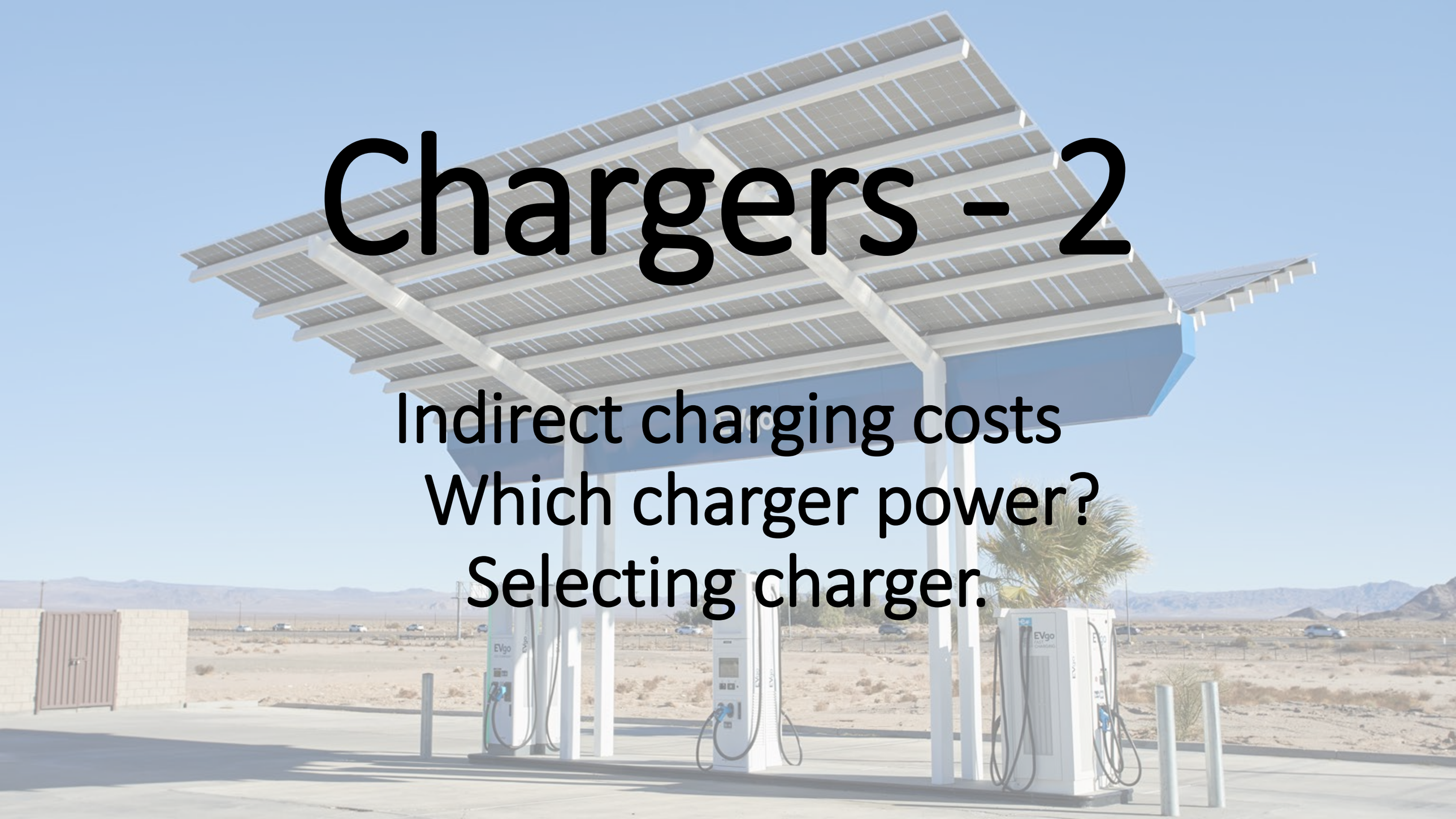
- Utilization the main factor for cost



- Charger power does not influence cost per kWh
- Land rent decreases with power



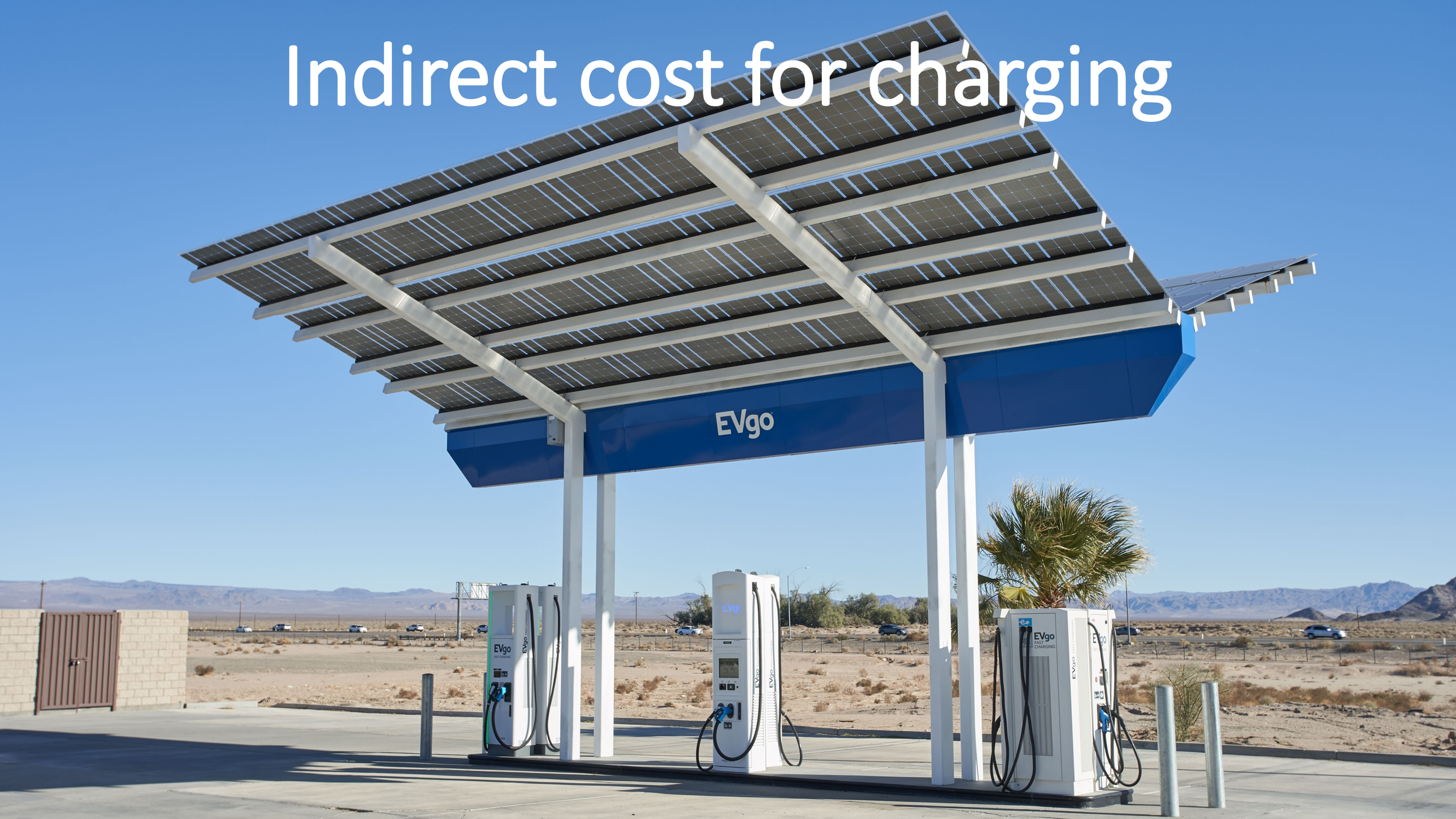




Chargers - 2

Indirect charging costs
Which charger power?
Selecting charger.

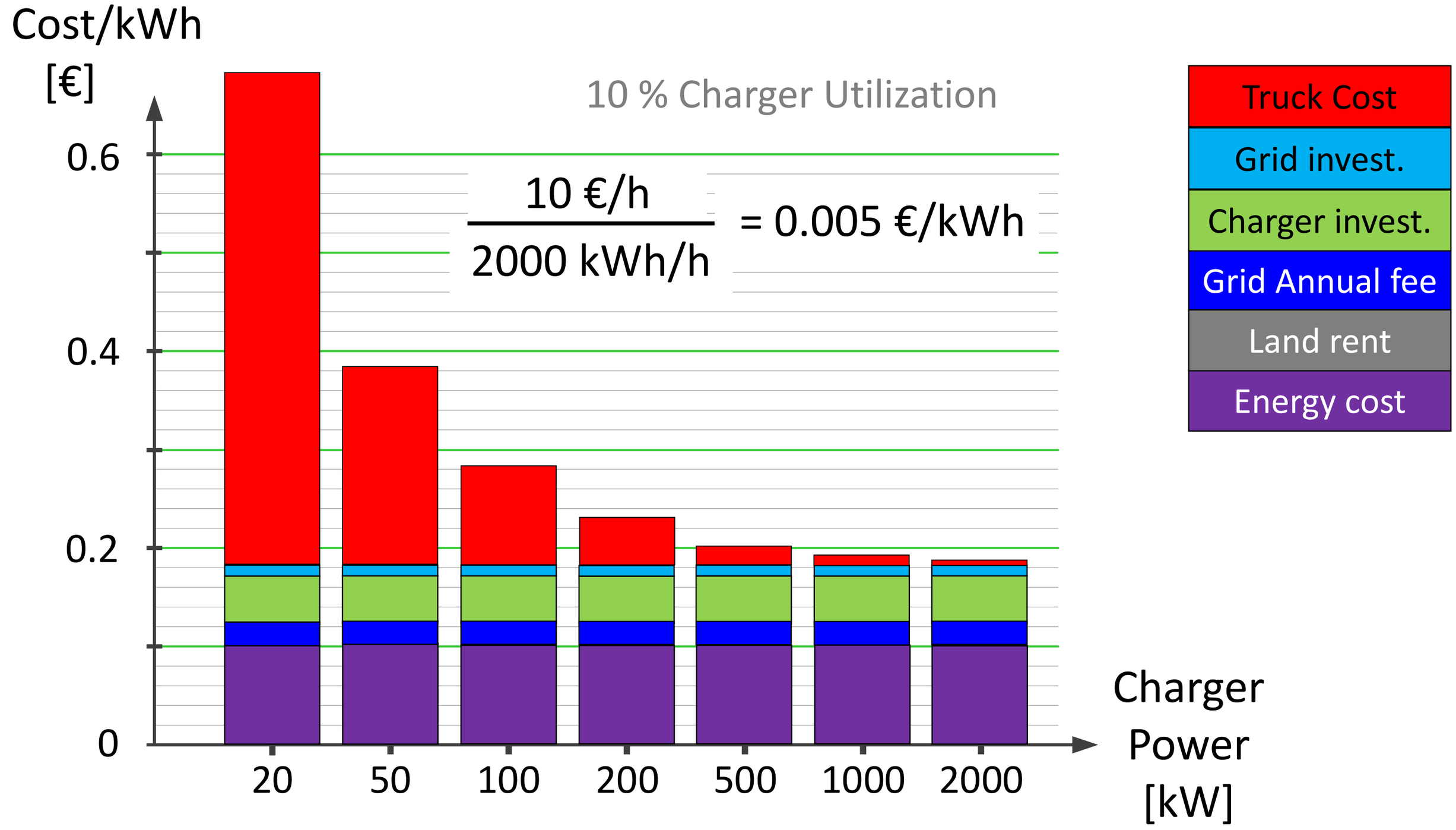
Indirect cost for charging

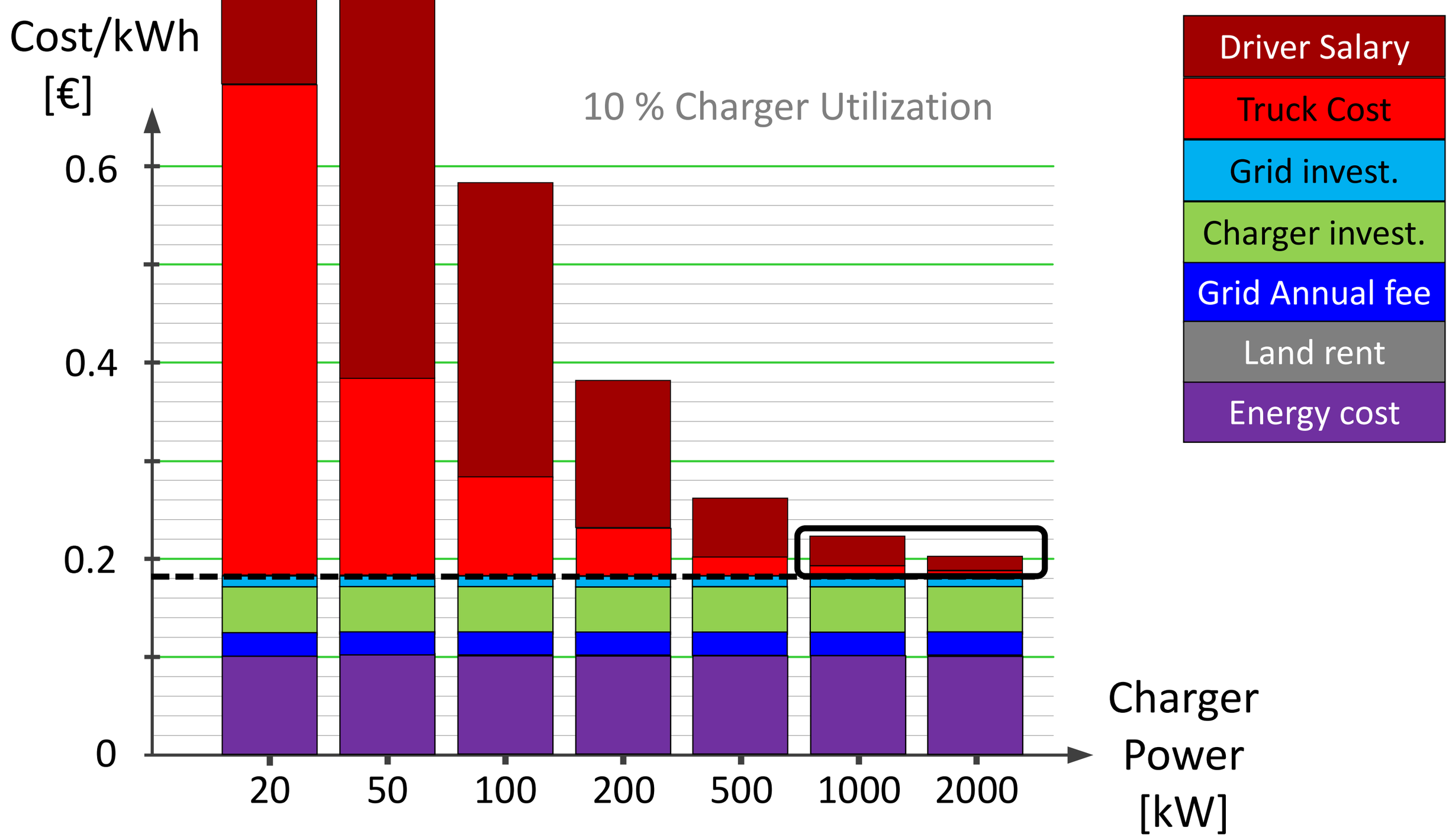


Indirect charging costs

Driver needs to wait = 30 €/h

Truck needs to wait = 10 €/h


Cost/kWh
[€]
10 % Charger Utilization
10 €/h
2000 kWh/h
= 0.005 €/kWh
0.6
0.4
0.2
0
20
50
100
200
500
1000
2000
Charger
Power
[kW]
Truck Cost
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost


Cost/kWh
[€]
10 % Charger Utilization
0.6
0.4
0.2
0
20
50
100
200
500
1000
2000
Charger
Power
[kW]
Driver Salary
Truck Cost
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost

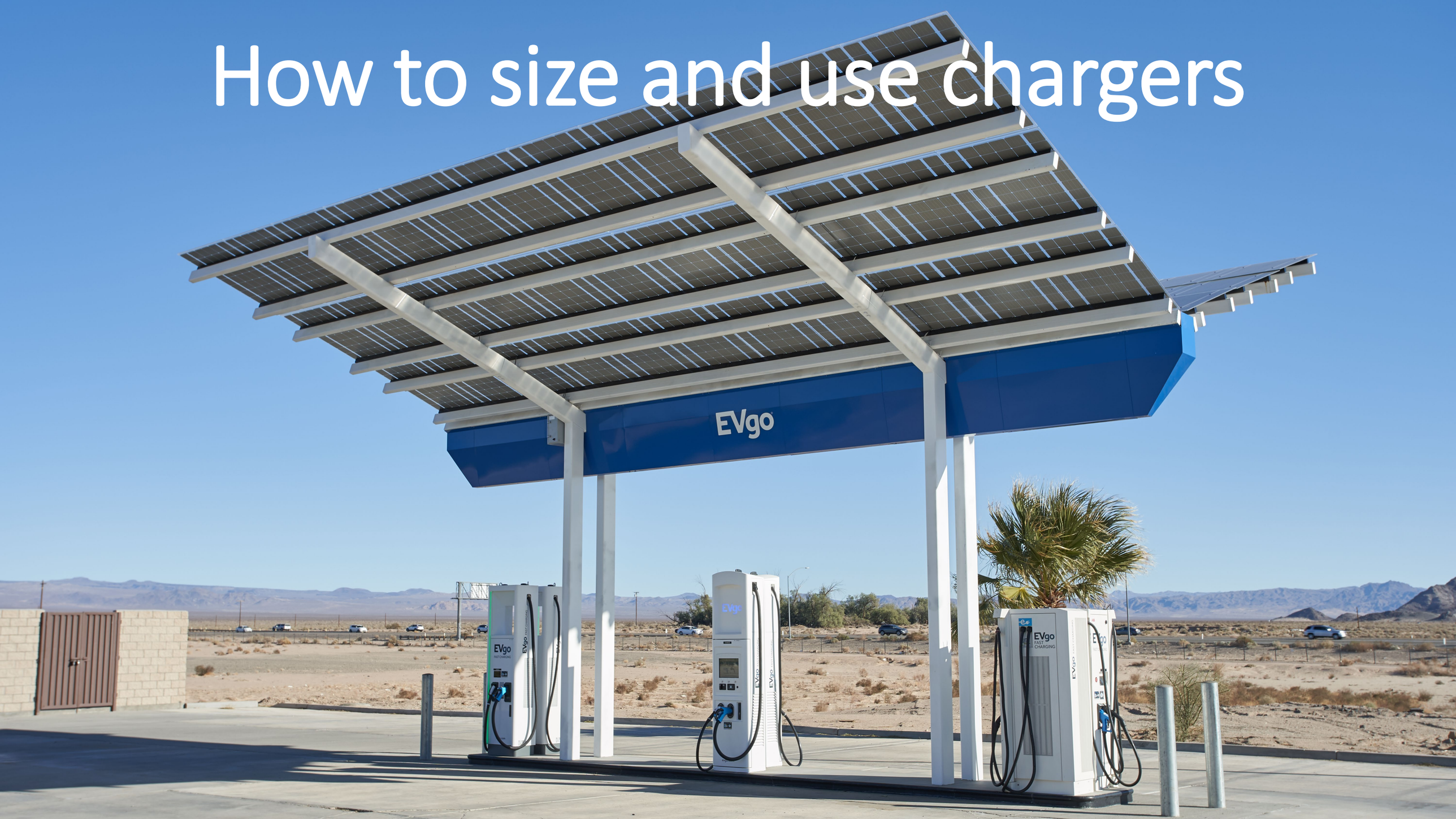
Indirect charging costs

Expensive to let driver and vehicle wait

except at ≥ 1000 kW charger power

⇒ *Charge @ breaks, or when stopped for other reasons*

How to size and use chargers



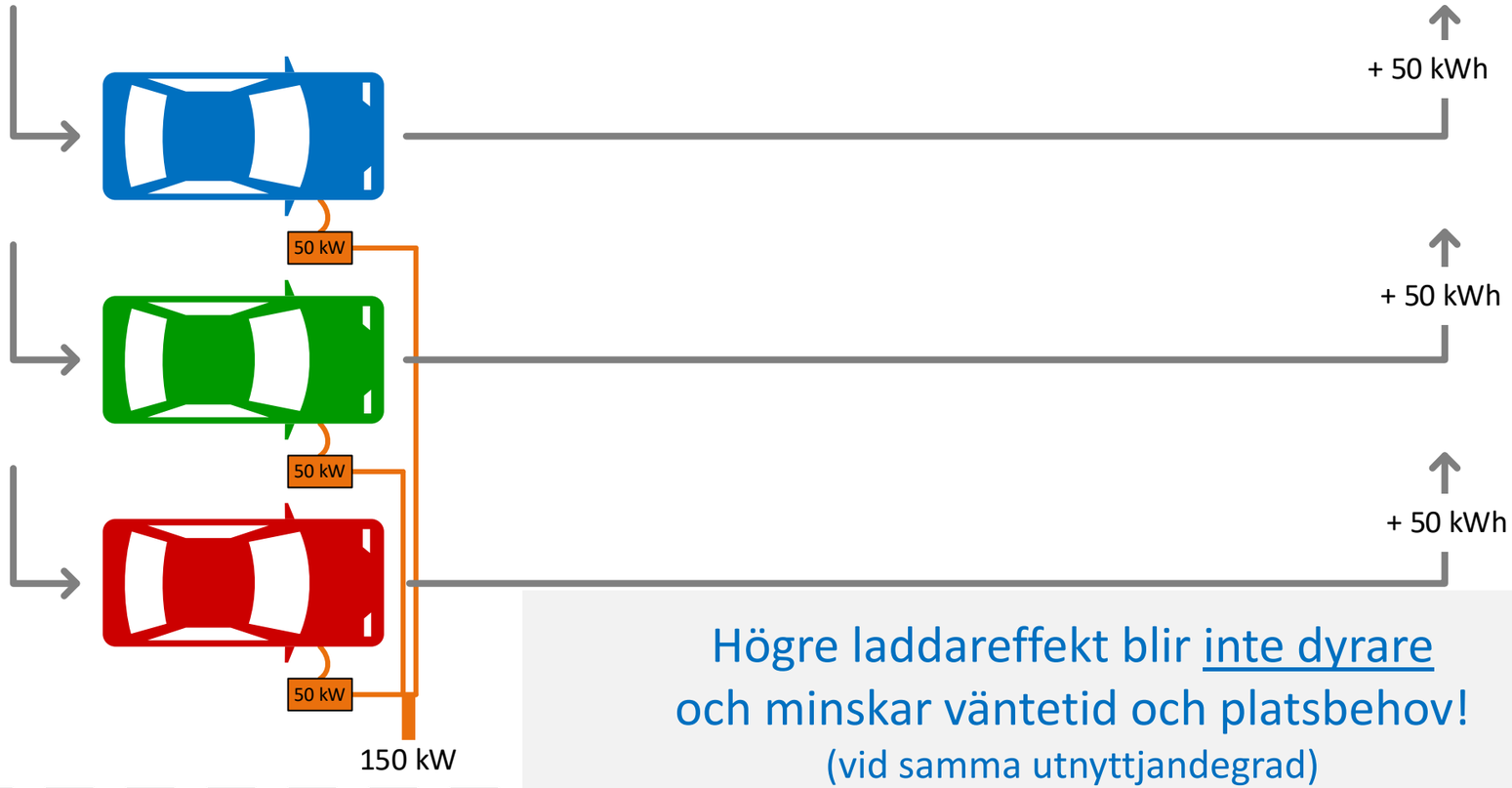
Påstående:

Laddplatser: Välj så hög effekt som möjligt!

Förklaringsexempel:

Tre bilar skall ladda 50 kWh

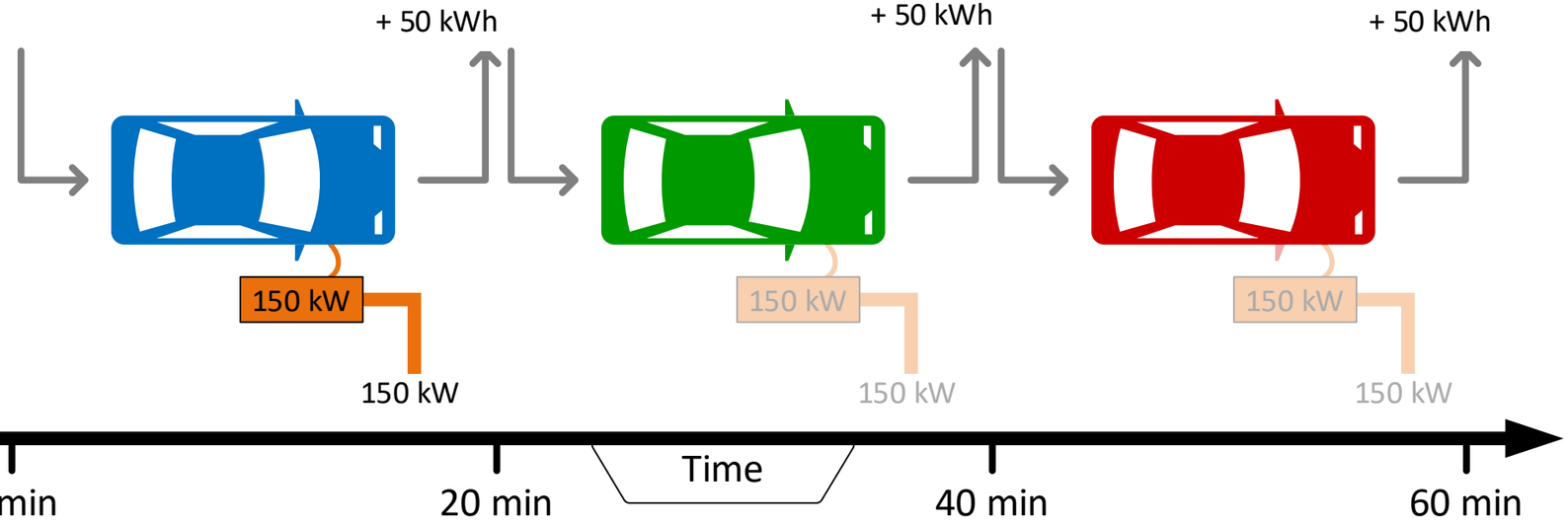
(medan förarna väntar)



Högre laddareffekt blir inte dyrare
och minskar väntetid och platsbehov!
(vid samma utnyttjandegrad)

Laddare:	3*50 kW
Elnät:	150 kW
Energi:	3*50 kWh
P-platser:	3 st
Väntetid:	3*60 min

”Lika dyrt”



Laddare:	1*150 kW
Elnät:	150 kW
Energi:	3*50 kWh
P-platser:	1 st
Väntetid:	3*20 min

Påstående:
Parkeringar med laddning: Så låg effekt som möjligt!

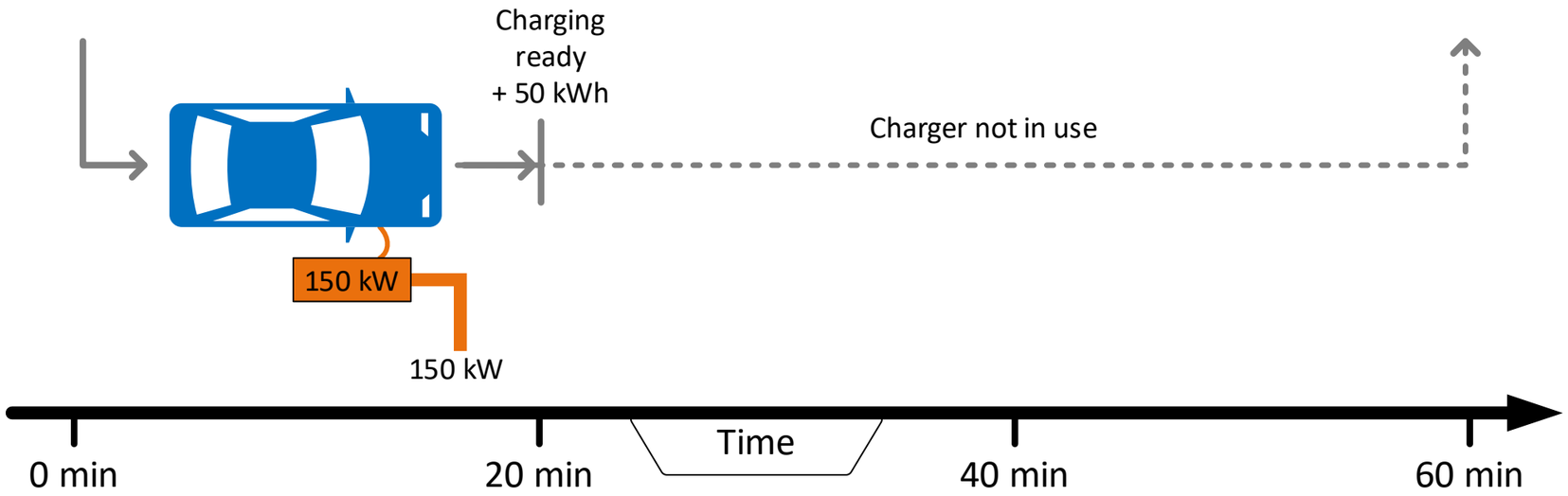
Förklaringsexempel:
En bil skall ladda 50 kWh
under lunch/middagsstopp.

Laddare: 50 kW
Elnät: 50 kW
Energi: 50 kWh
P-platser: 1 st
Väntetid: 0 min

Laddare på ställen man parkerar skall inte ha högre effekt än

Energin man vill ladda / tiden man parkerar

3 ggr dyrare laddare
för samma energi



Laddare: 150 kW
Elnät: 150 kW
Energi: 50 kWh
P-platser: 1 st
Väntetid: 0 min

Olika typer av laddningstillfällen

- Egen laddare där bilen ändå står uppställd

  (Nattparkeringsladdare, egen terminalport)

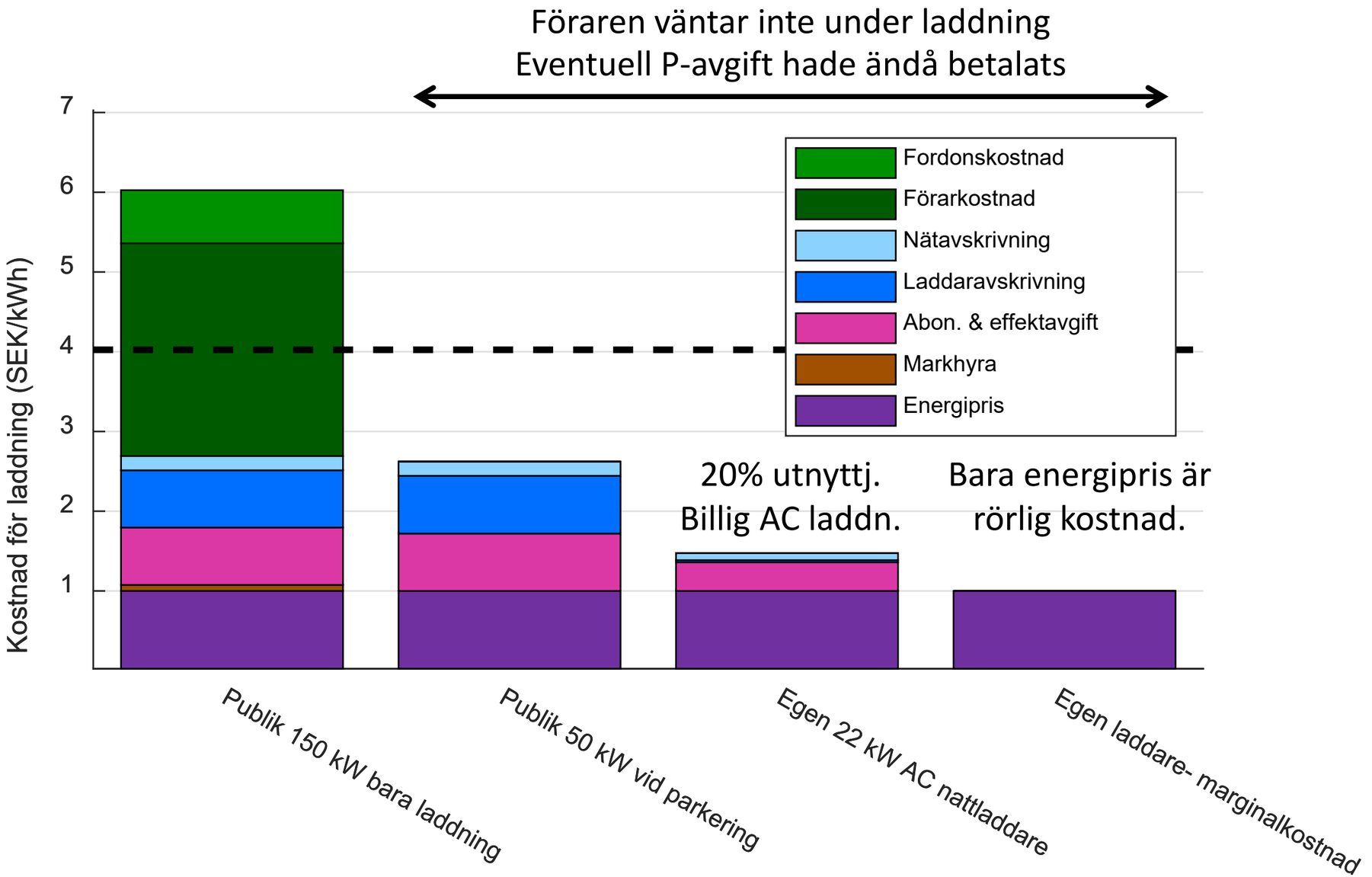
- Publika laddare där man ändå skulle parkerat.

  (Annans lastport, Lunch/rastställen, …)

- Publika laddare där man bara stannar för att ladda

  (står och väntar eller fördriver tiden med fika)

Kostnad för olika typer av laddningstillfällen

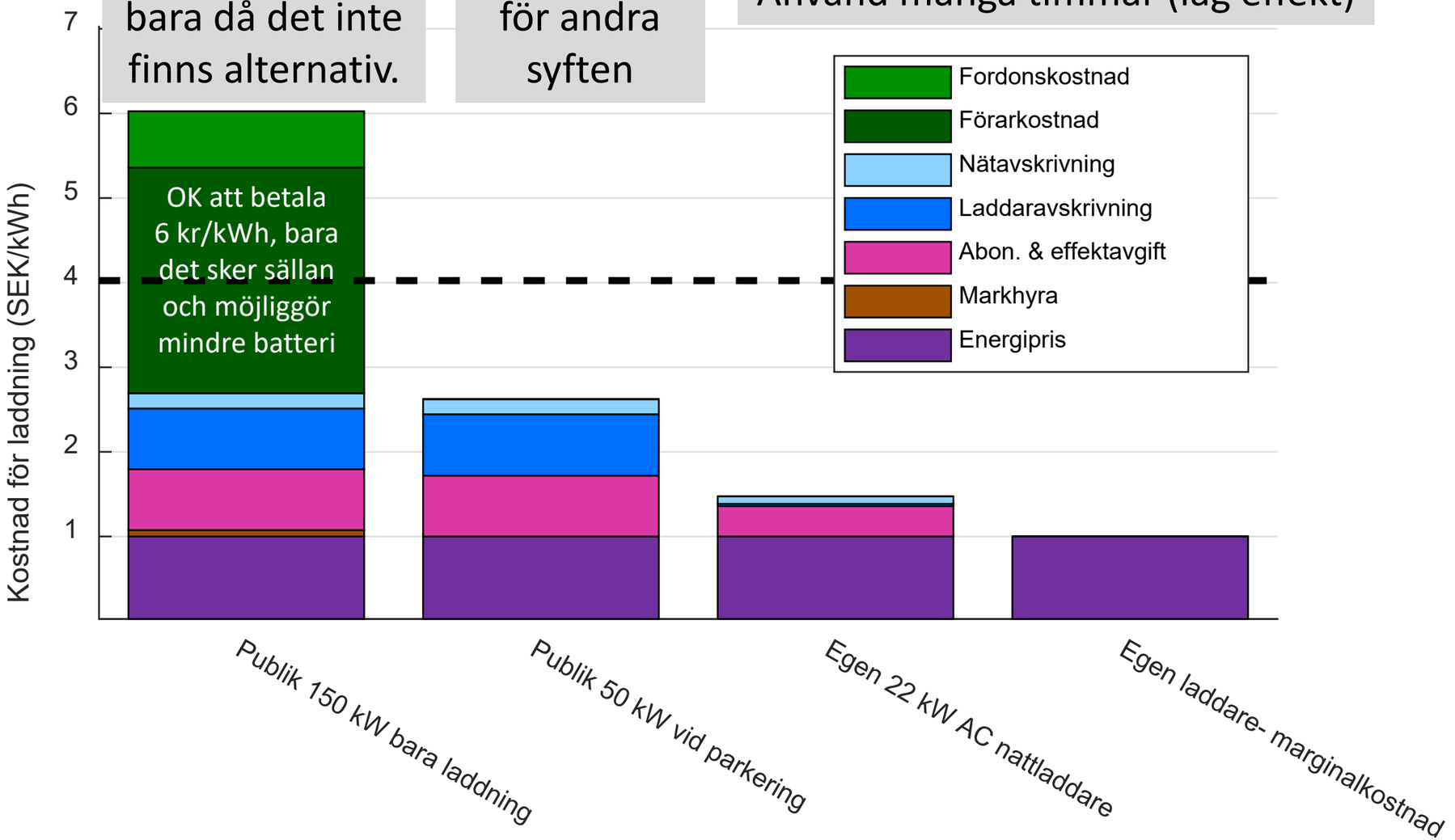


Kostnad för olika typer av laddningstillfällen

3) Publik snabbladdning bara då det inte finns alternativ.

2) Ladda under stopp för andra syften

1) Prioritera nattladdning. Använd många timmar (låg effekt)



Pricing unclear
(may vary a lot with time and place)

Availability vs. High utilization

Summary Chargers

- No technical limit for charger power – MW possible for large trucks
- Grid investment < 20% of fixed costs
- Cost/kWh depend on utilization (preferably ≥10%)
- Cost/kWh independent of charger power
- Avoid extra driver time (acceptable at high charge power)
- Parking places: Select “lowest” charger power
- Public fast chargers: Select Highest power vehicle (Battery) can take
- Charge priority:

  1) Parked “at home” 2) parked elsewhere 3) public fast charge

Electric Vehicles - 1

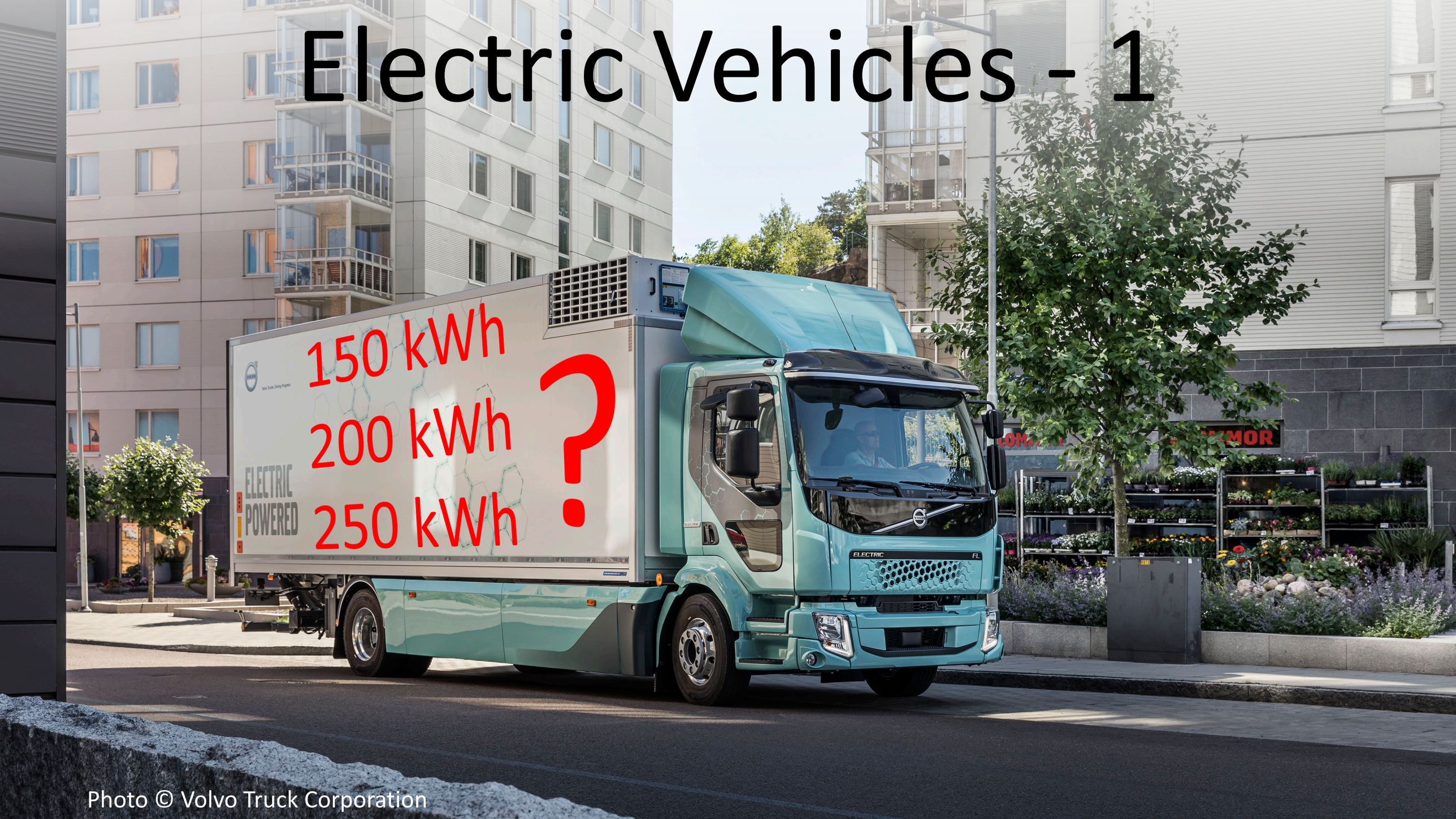
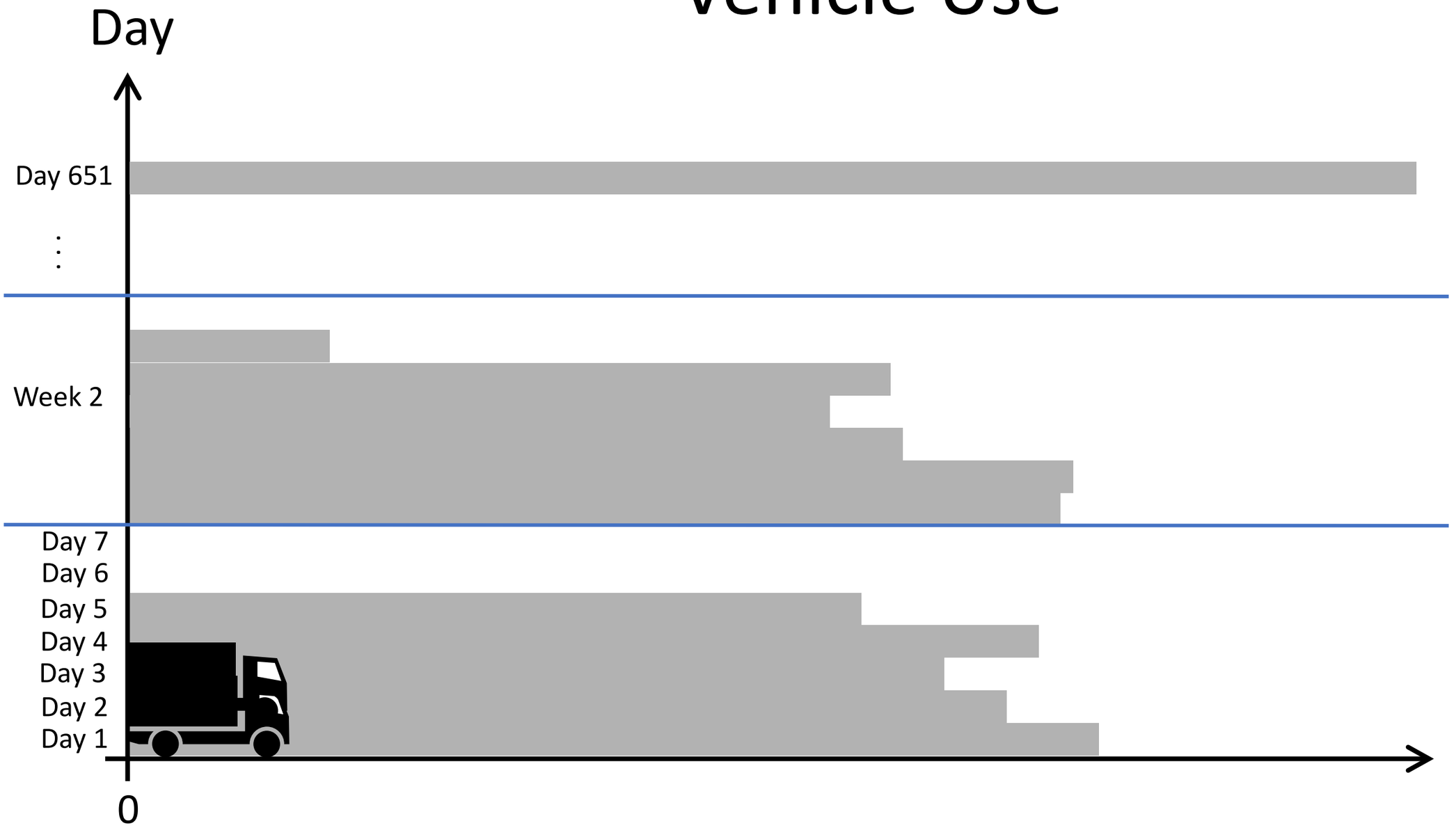


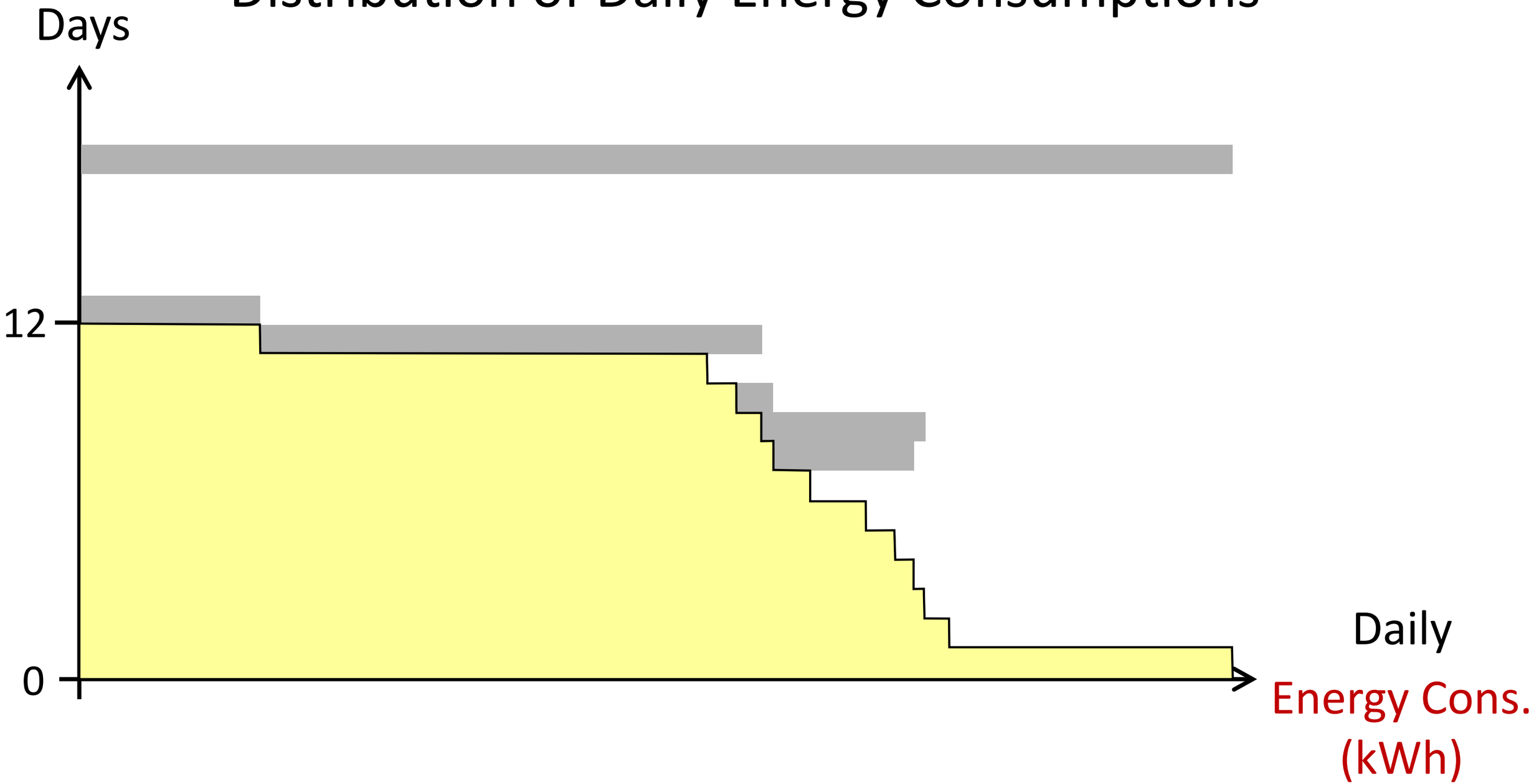
Photo © Volvo Truck Corporation

Vehicle Use and Energy Distribution

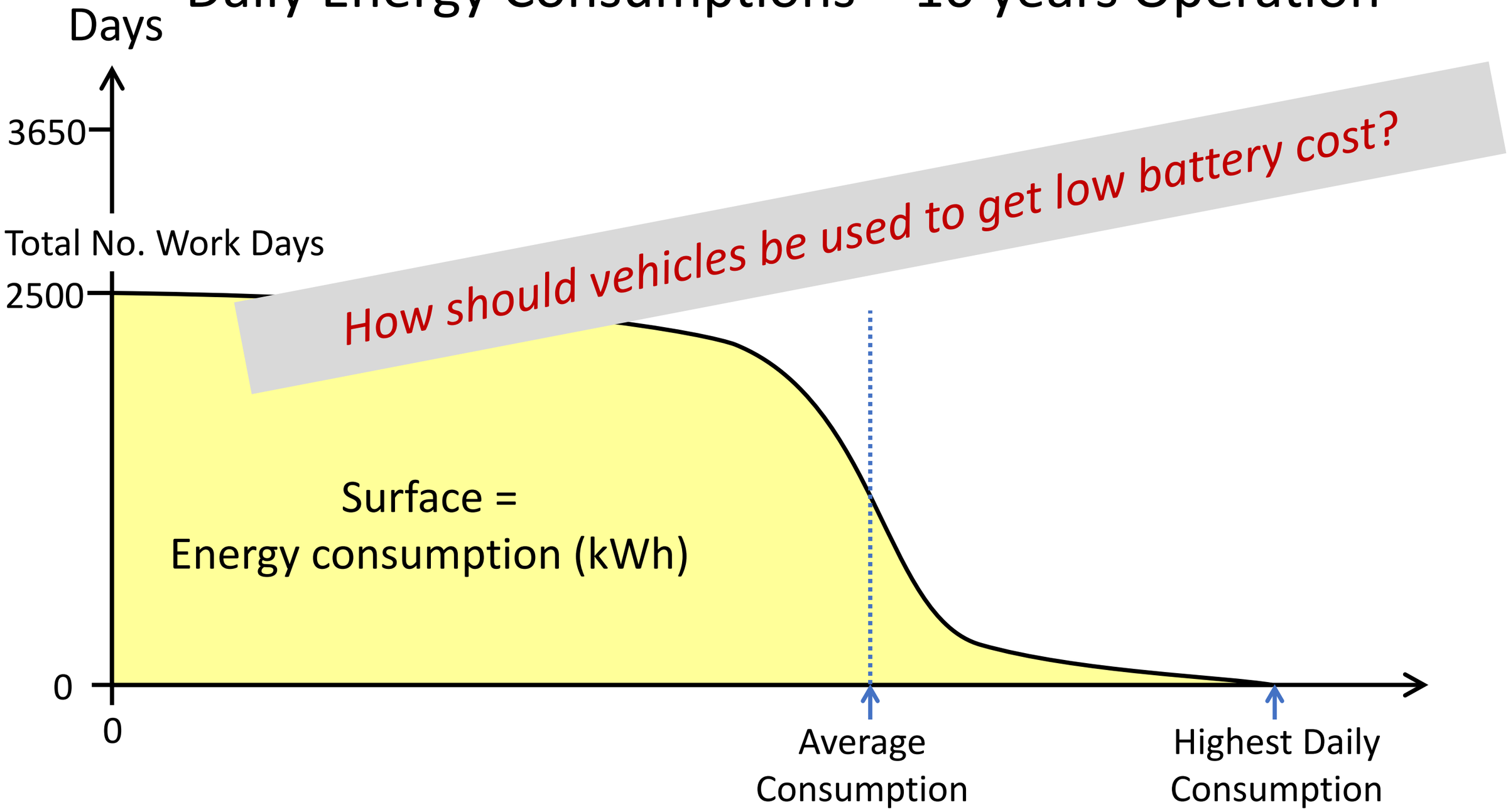
Vehicle Use


Day
Day 651
Week 2
Day 7
Day 6
Day 5
Day 4
Day 3
Day 2
Day 1
0
Daily
Energy Cons.
(kWh)

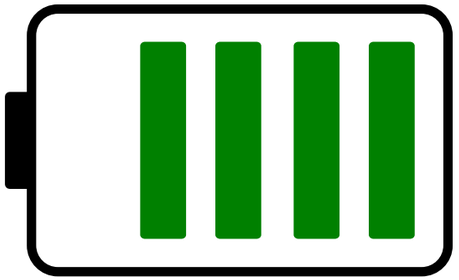
Distribution of Daily Energy Consumptions



Daily Energy Consumptions – 10 years Operation

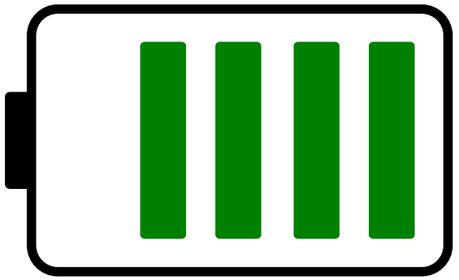


Battery Utilization and Cost/kWh



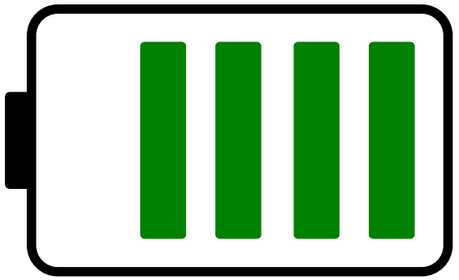
$$\frac{100\ \text{kWh} \times 200\ €/\text{kWh}}{160'000\ \text{kWh}} = \frac{20'000\ €}{160'000\ \text{kWh}} = 0.125\ €/\text{kWh}$$

$$\frac{\text{Battery Capacity} \times \text{Battery Price}}{\text{Total Delivered Energy}} = \text{Cost per kWh}$$



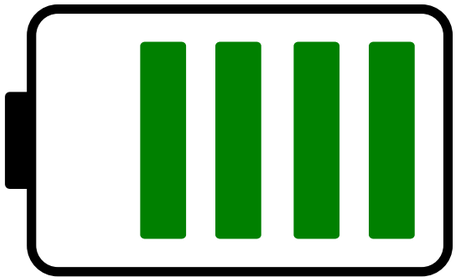
$$\frac{100\ \text{kWh} \times 200\ €/\text{kWh}}{160'000\ \text{kWh}} = \frac{20'000\ €}{160'000\ \text{kWh}} = 0.125\ €/\text{kWh}$$

$$\frac{\text{Battery Price}}{\text{Battery Utilization}} = \text{Cost per kWh}$$



$$\frac{100\ \text{kWh} \times 200\ €/\text{kWh}}{160'000\ \text{kWh}} = \frac{20'000\ €}{160'000\ \text{kWh}} = 0.125\ €/\text{kWh}$$

$$\frac{\text{Battery Price}}{\text{Battery Utilization}} = \text{Cost per kWh}$$

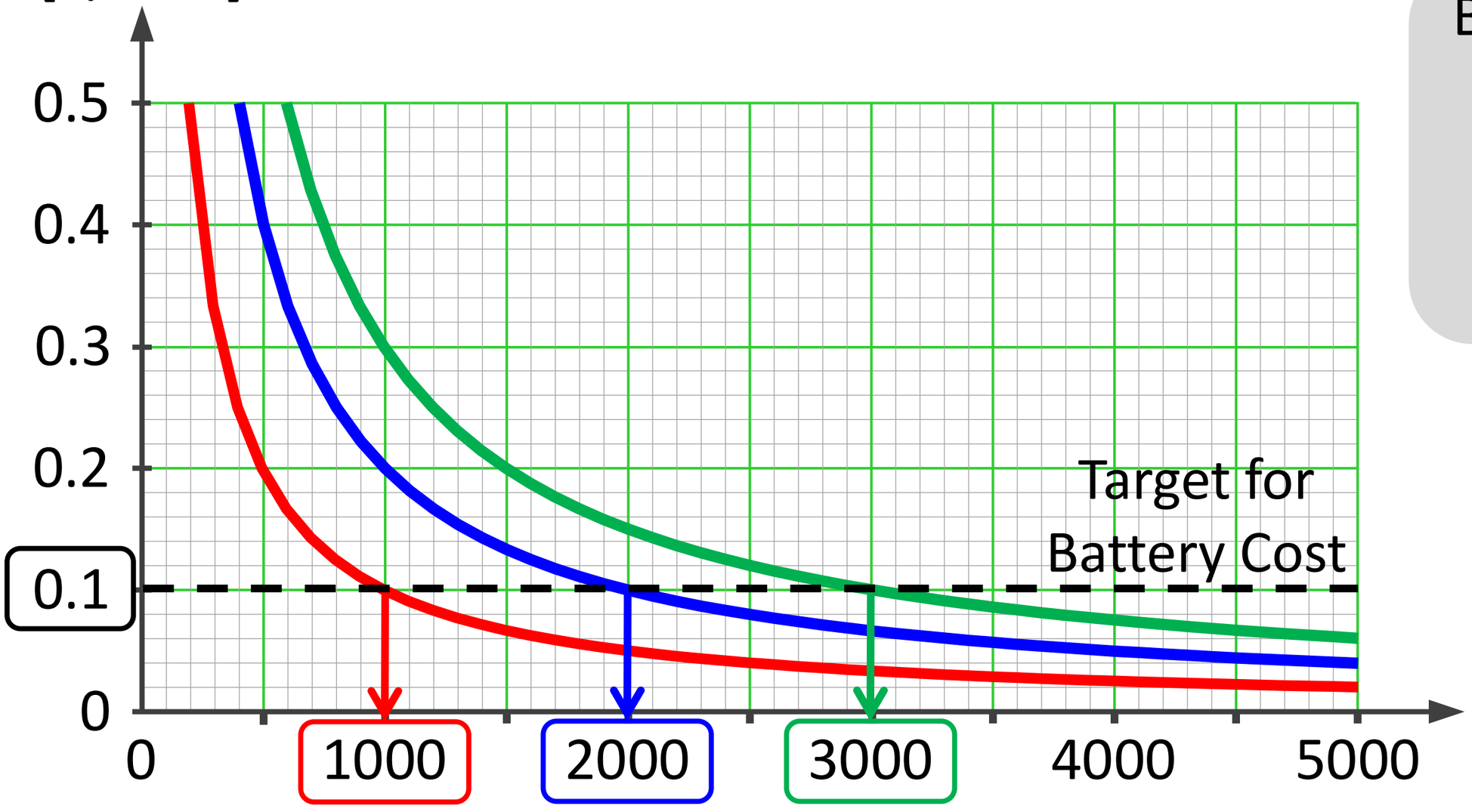


$$\frac{100\ \text{kWh} \times 200\ €/\text{kWh}}{160'000\ \text{kWh}} = \frac{20'000\ €}{160'000\ \text{kWh}} = 0.125\ €/\text{kWh}$$

$$\text{Cost per kWh} = \frac{\text{Battery Price}}{\text{Battery Utilization}}$$

$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}}\ [\text{EFC}]$$

$$\text{Battery Cost} = \frac{\text{Battery Price}}{\text{Battery Utilization}}$$



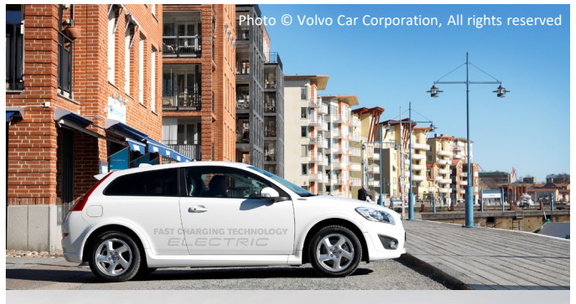
Battery Price

300 €/kWh

200 €/kWh

100 €/kWh

$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}}$$



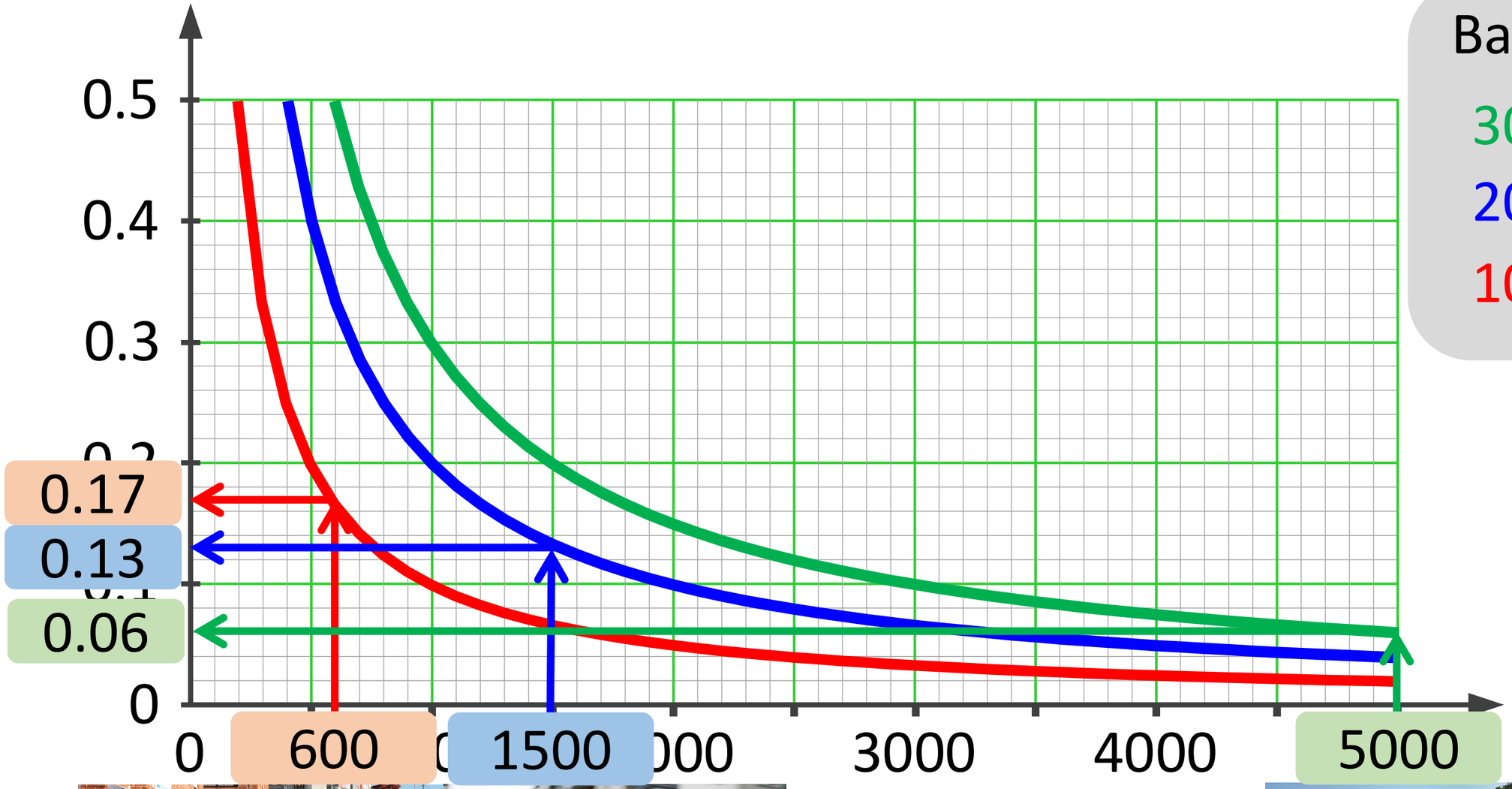
$$\frac{150'000\ \text{km} \times 0.16\ \text{kWh/km}}{40\ \text{kWh}} = \textbf{600 EFC}$$

$$\frac{250'000\ \text{km} \times 0.24\ \text{kWh/km}}{80\ \text{kWh}} = \textbf{750 EFC}$$

$$\frac{125\ \text{kWh/day} \times 2400\ \text{day}}{200\ \text{kWh}} = \textbf{1500 EFC}$$

$$\frac{500\ \text{kWh/day} \times 3000\ \text{day}}{300\ \text{kWh}} = \textbf{5000 EFC}$$

Battery Cost [€/kWh]



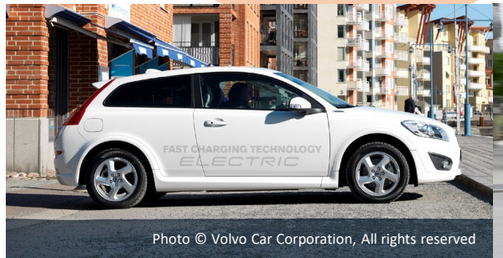
Battery Price

300 €/kWh

200 €/kWh

100 €/kWh

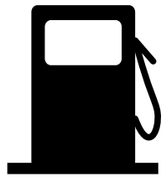
Battery Utilization [EFC]



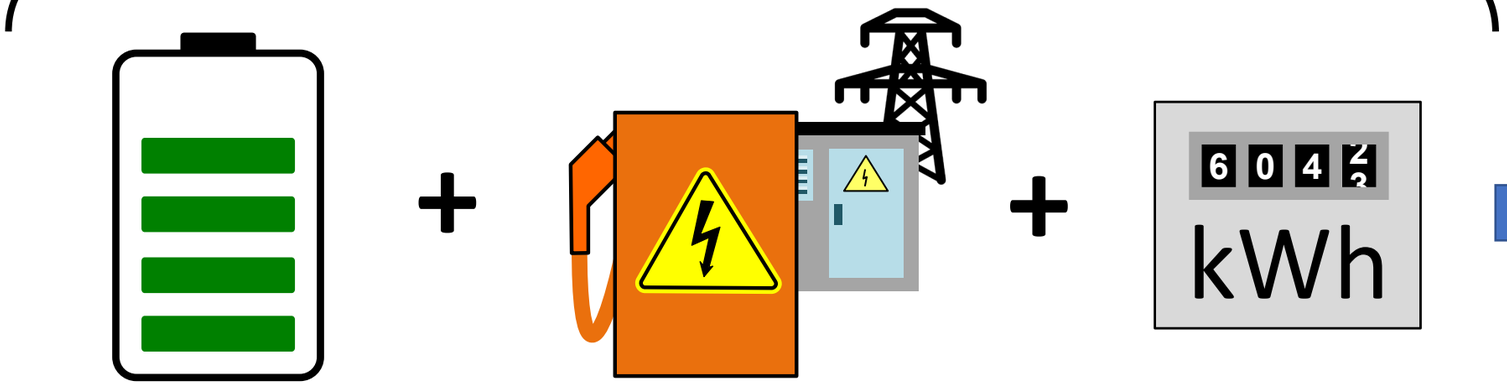
TCO for Trucks

Total Cost for Electric Trucks

Vehicle Price ≤ Price Combustion Engine Vehicle



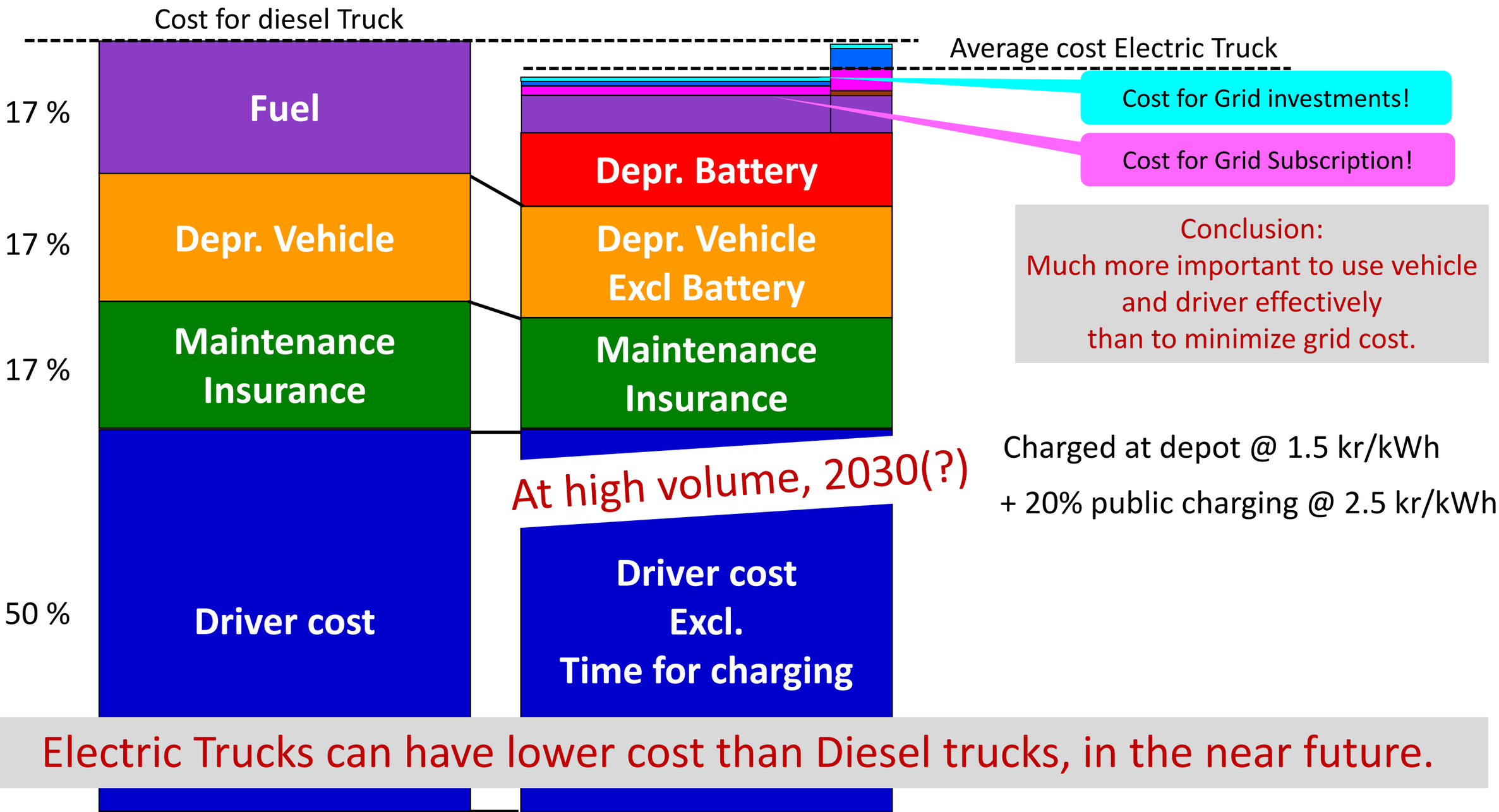
Diesel Cost ~ 0.4 €/kWh$_{Wheel}$



Should Cost
≤ 0.4 €/kWh

(May somewhere use
0.3 €/kWh instead)

Cost for a conventional and an Electric distribution truck

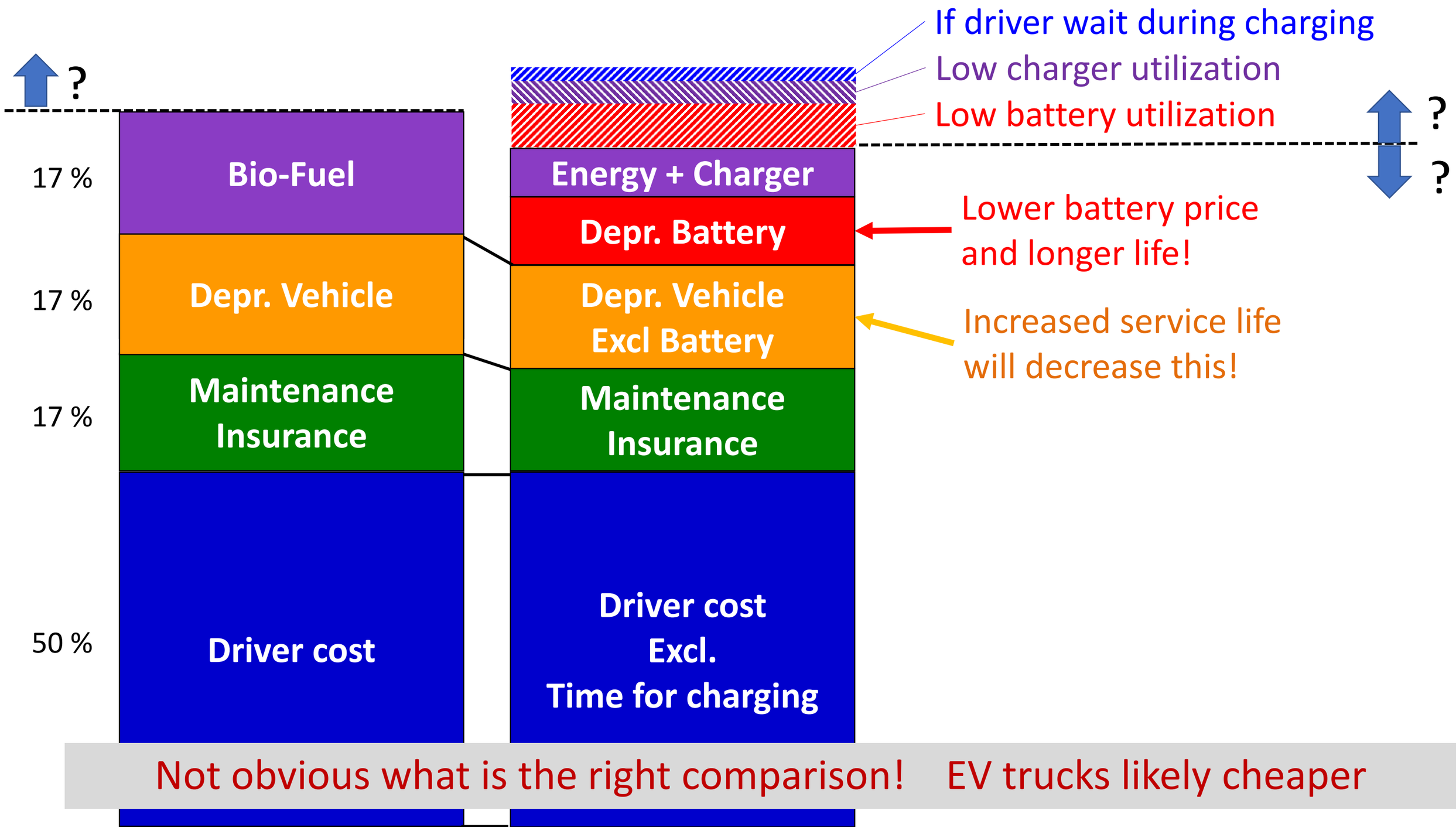


Conclusion:
Much more important to use vehicle and driver effectively than to minimize grid cost.

Charged at depot @ 1.5 kr/kWh

+ 20% public charging @ 2.5 kr/kWh

Electric Trucks can have lower cost than Diesel trucks, in the near future.


?
17 %
17 %
17 %
50 %
Bio-Fuel
Depr. Vehicle
Maintenance
Insurance
Driver cost
Energy + Charger
Depr. Battery
Depr. Vehicle
Excl Battery
Maintenance
Insurance
Driver cost
Excl.
Time for charging
If driver wait during charging
Low charger utilization
Low battery utilization
?
?
Lower battery price
and longer life!
Increased service life
will decrease this!
Not obvious what is the right comparison! EV trucks likely cheaper

Electric Vehicles - 2

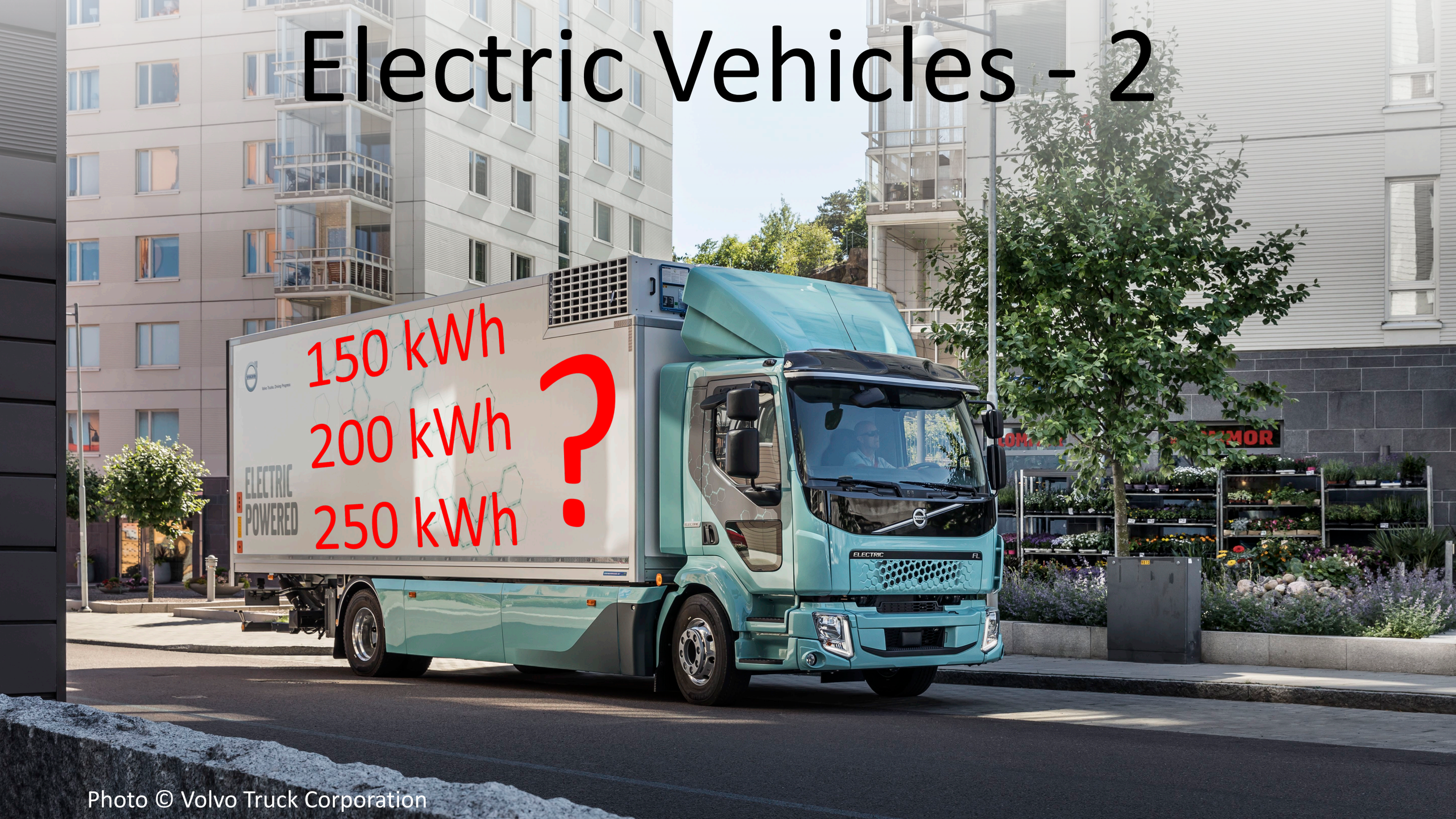
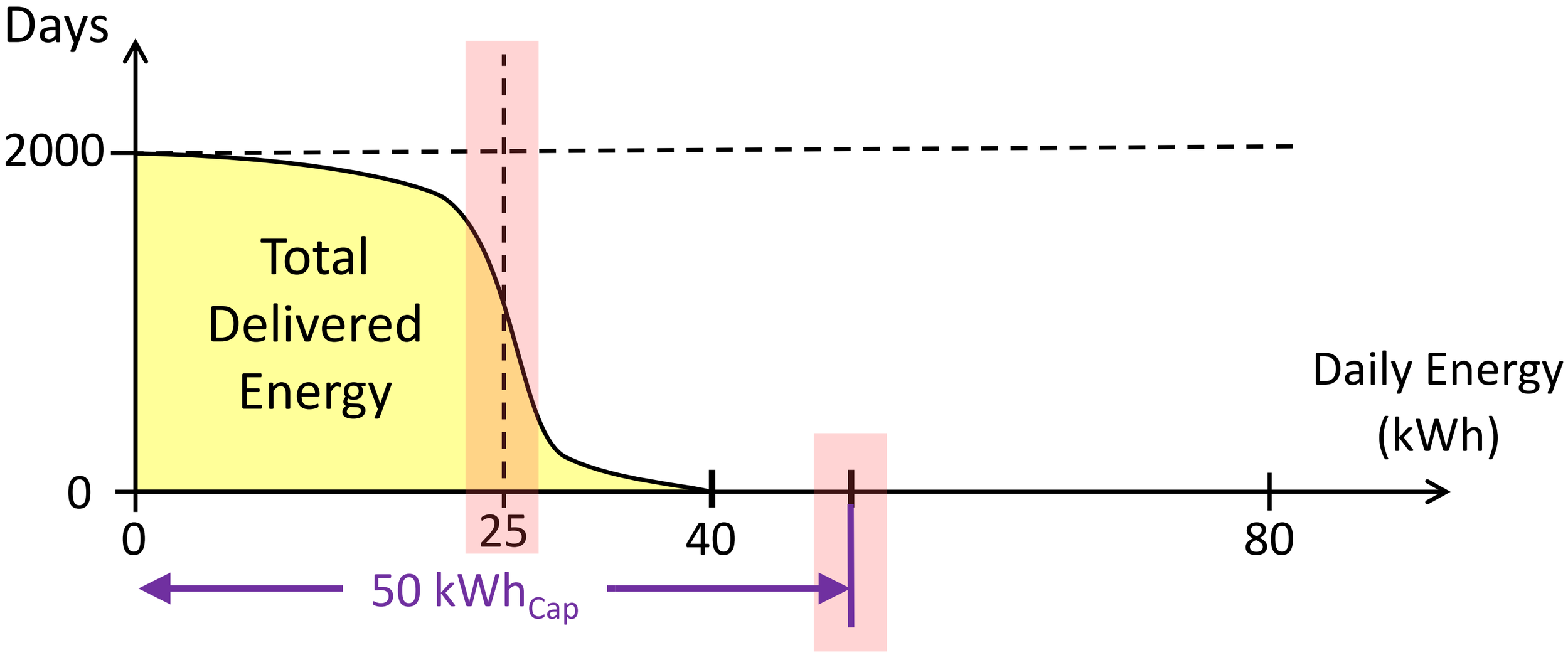


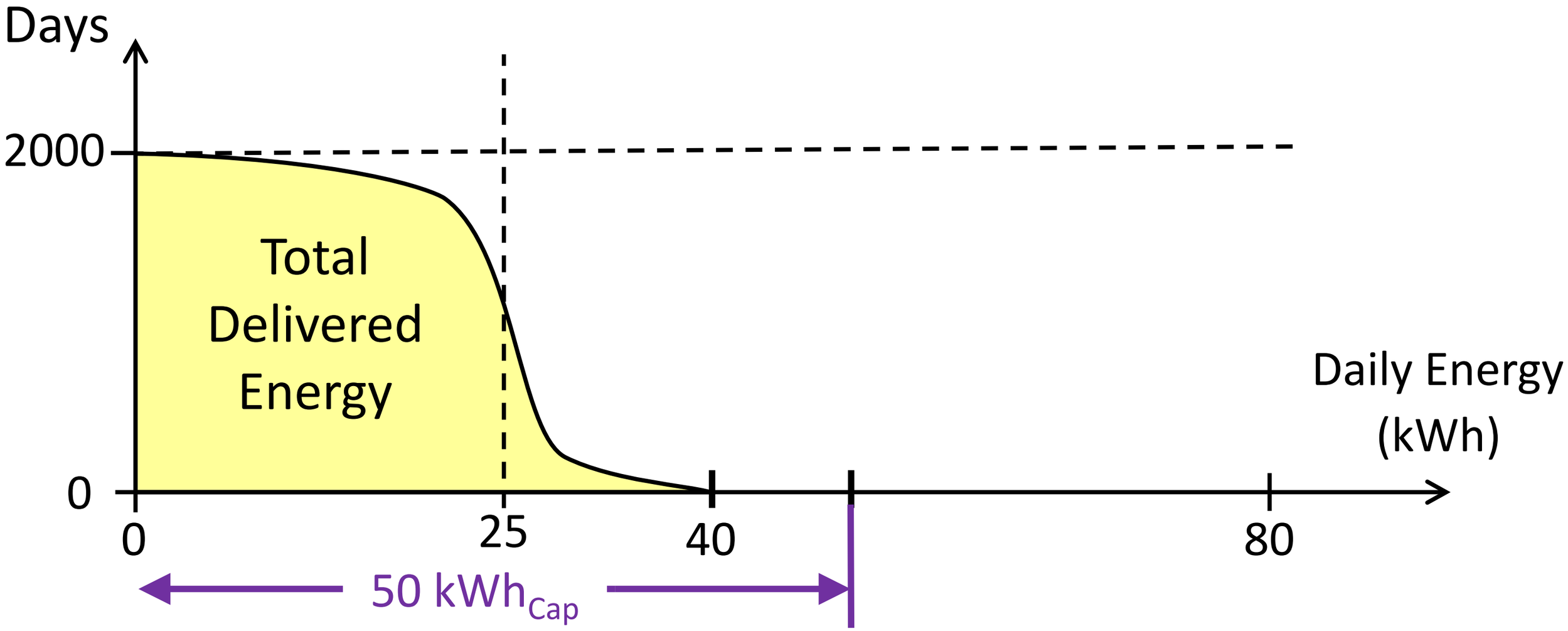
Photo © Volvo Truck Corporation

How to utilize the battery much

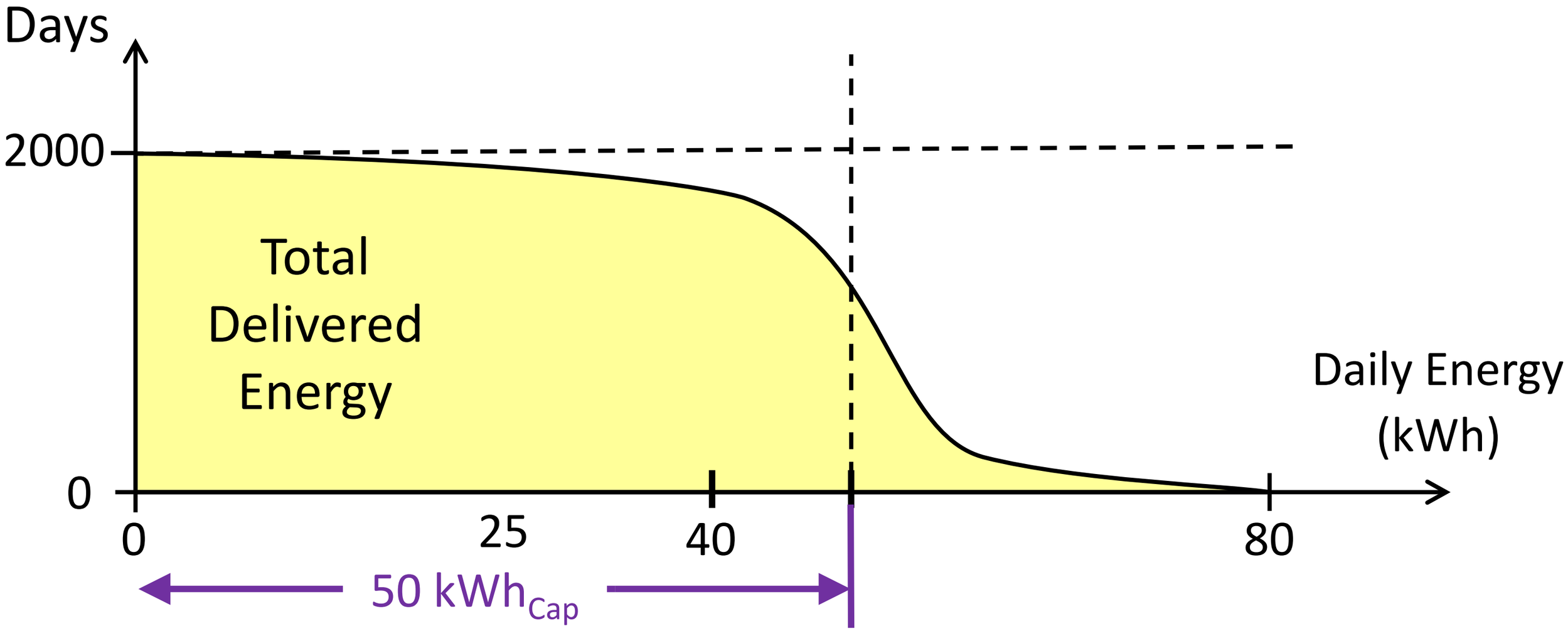
$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}} = \frac{2000 \times 25\ \text{kWh}}{50\ \text{kWh}} = 1000\ \text{EFC}$$



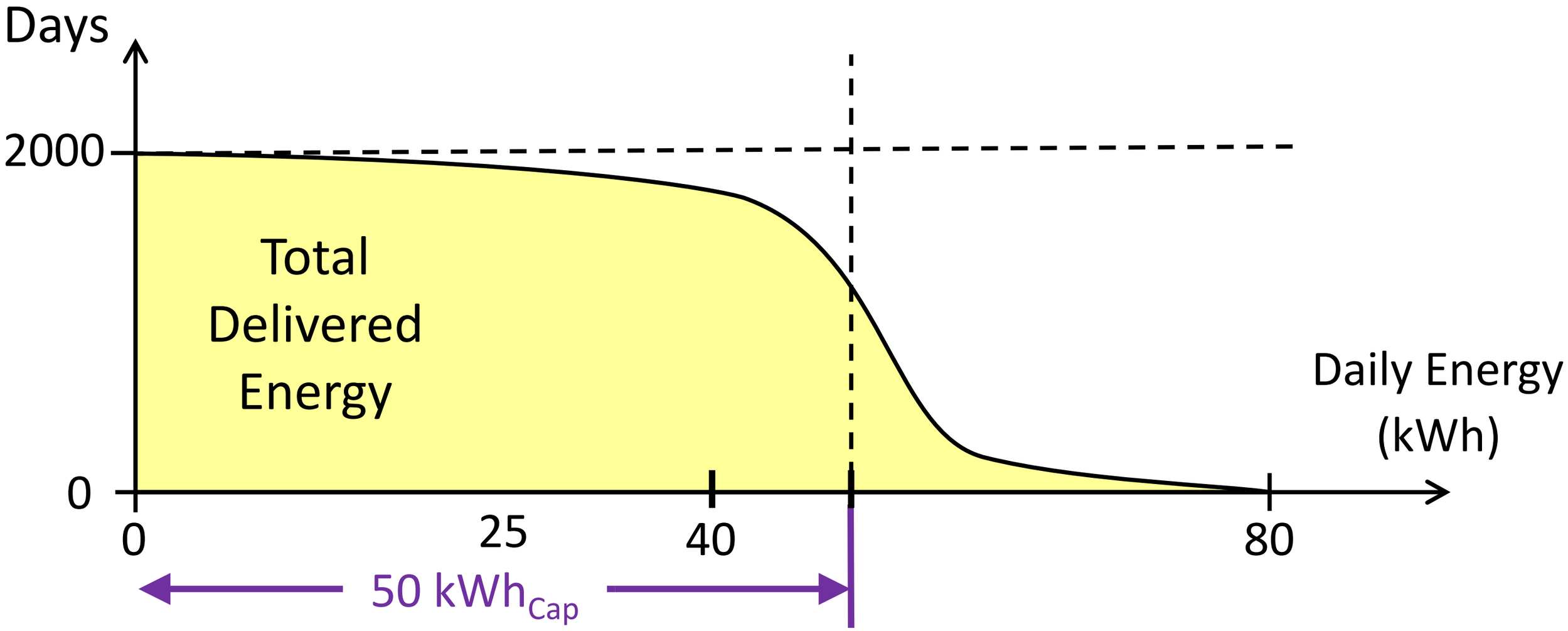
What if the vehicle drives longer per day?



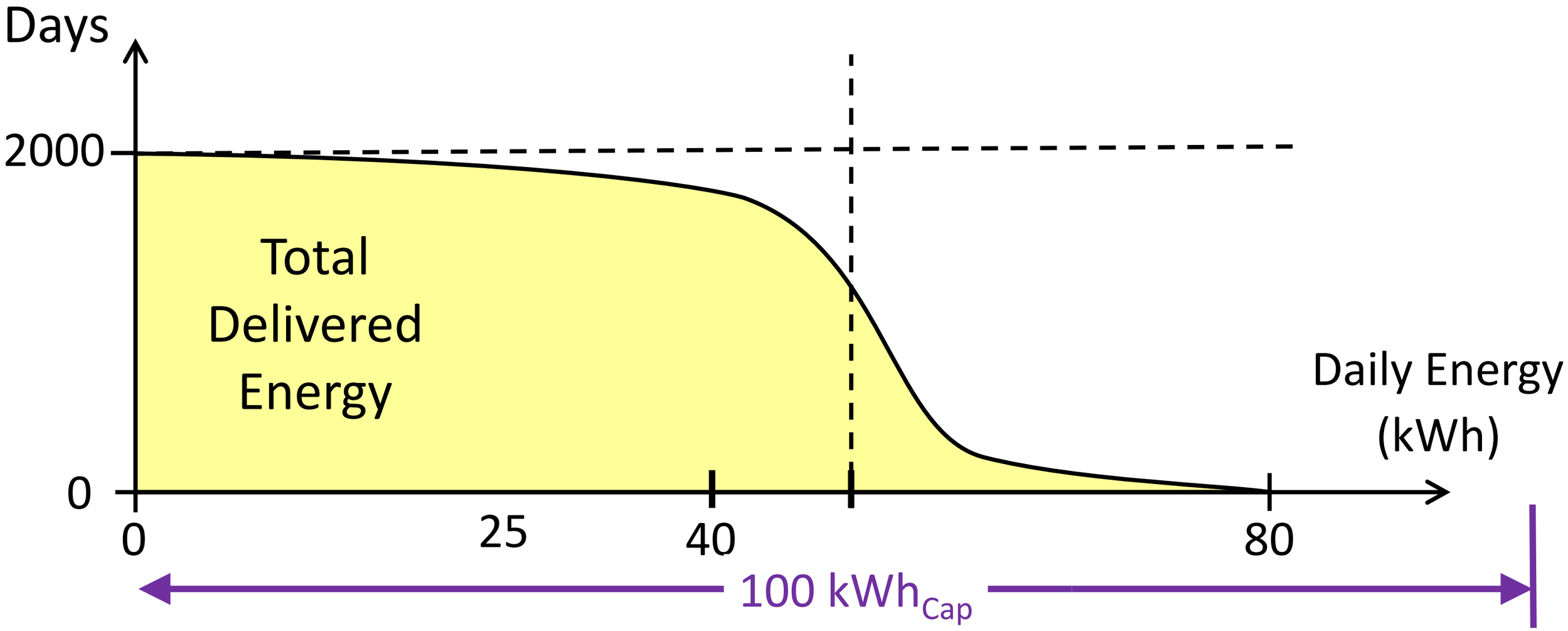
What if the vehicle drives longer per day?



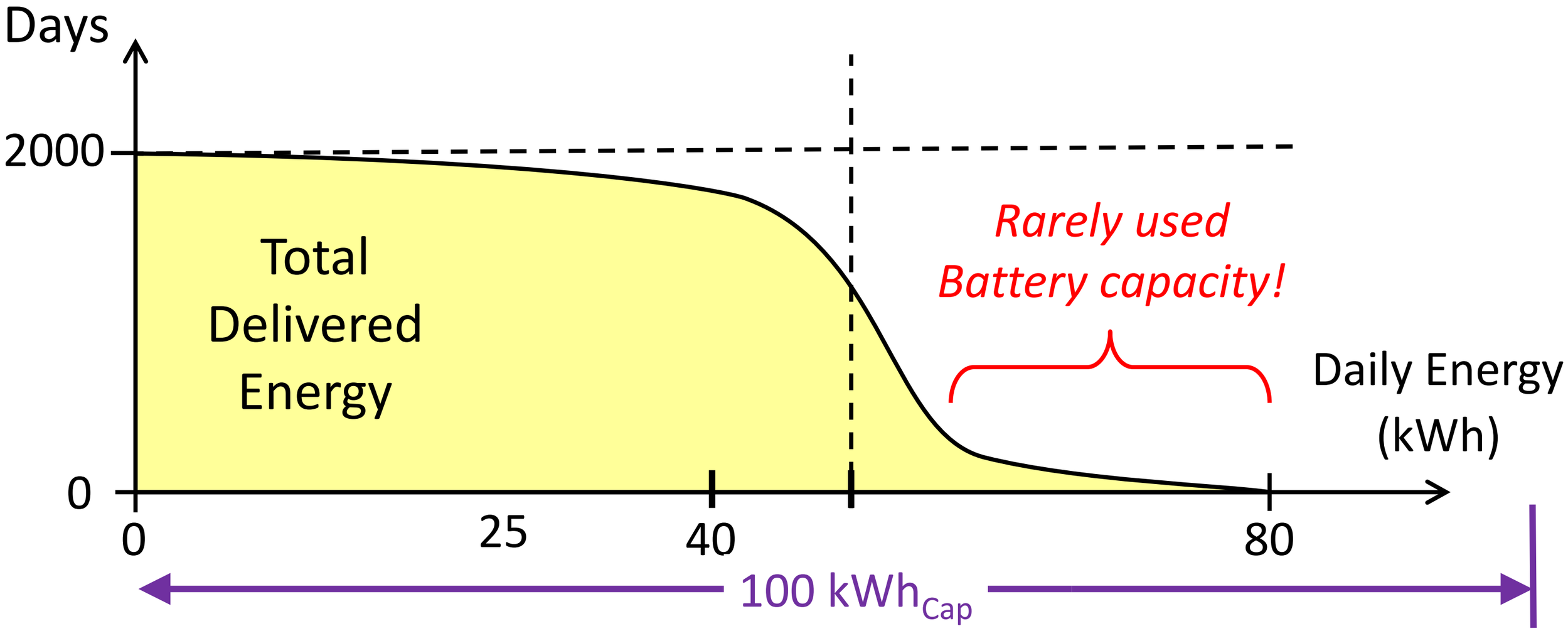
What if the vehicle drives longer per day?



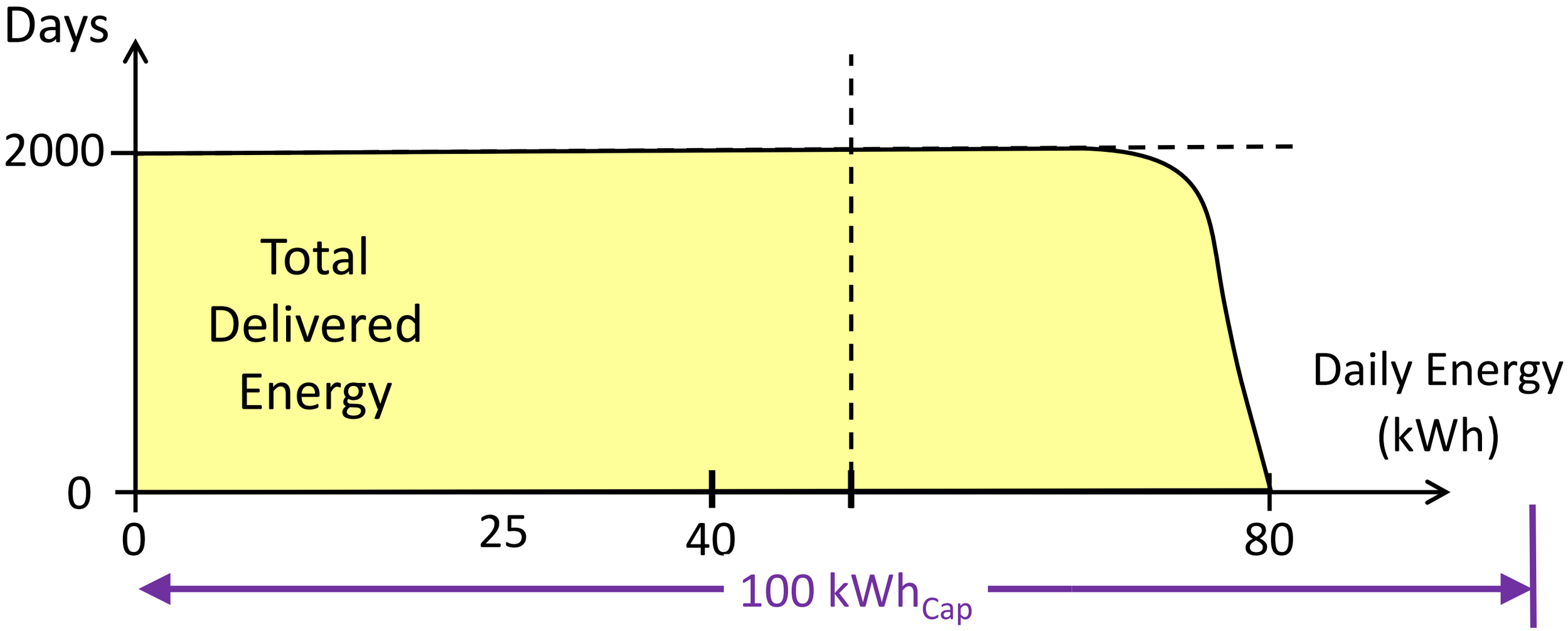
$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}} = \frac{2000 \times 50 \text{ kWh}}{100 \text{ kWh}} = 1000 \text{ EFC}$$



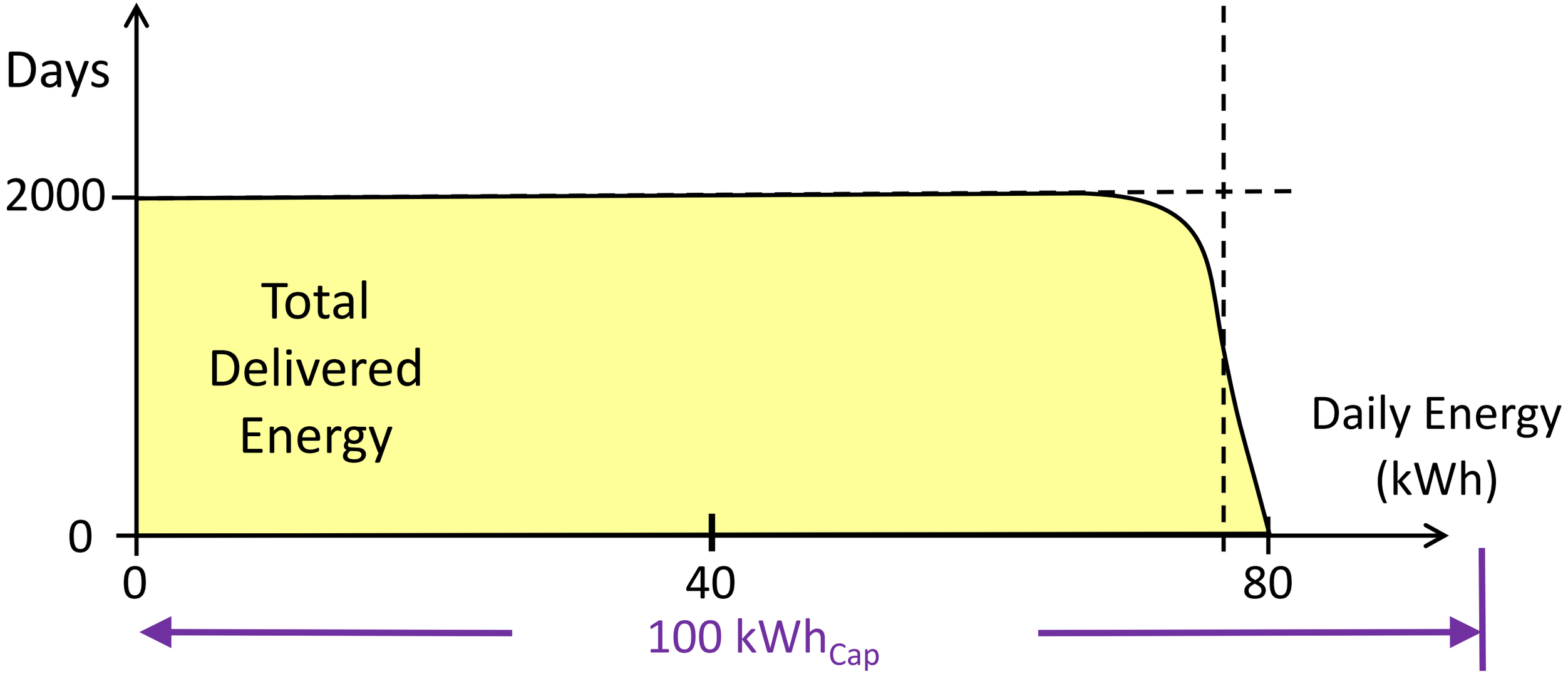
What can reduce the battery cost per kWh?



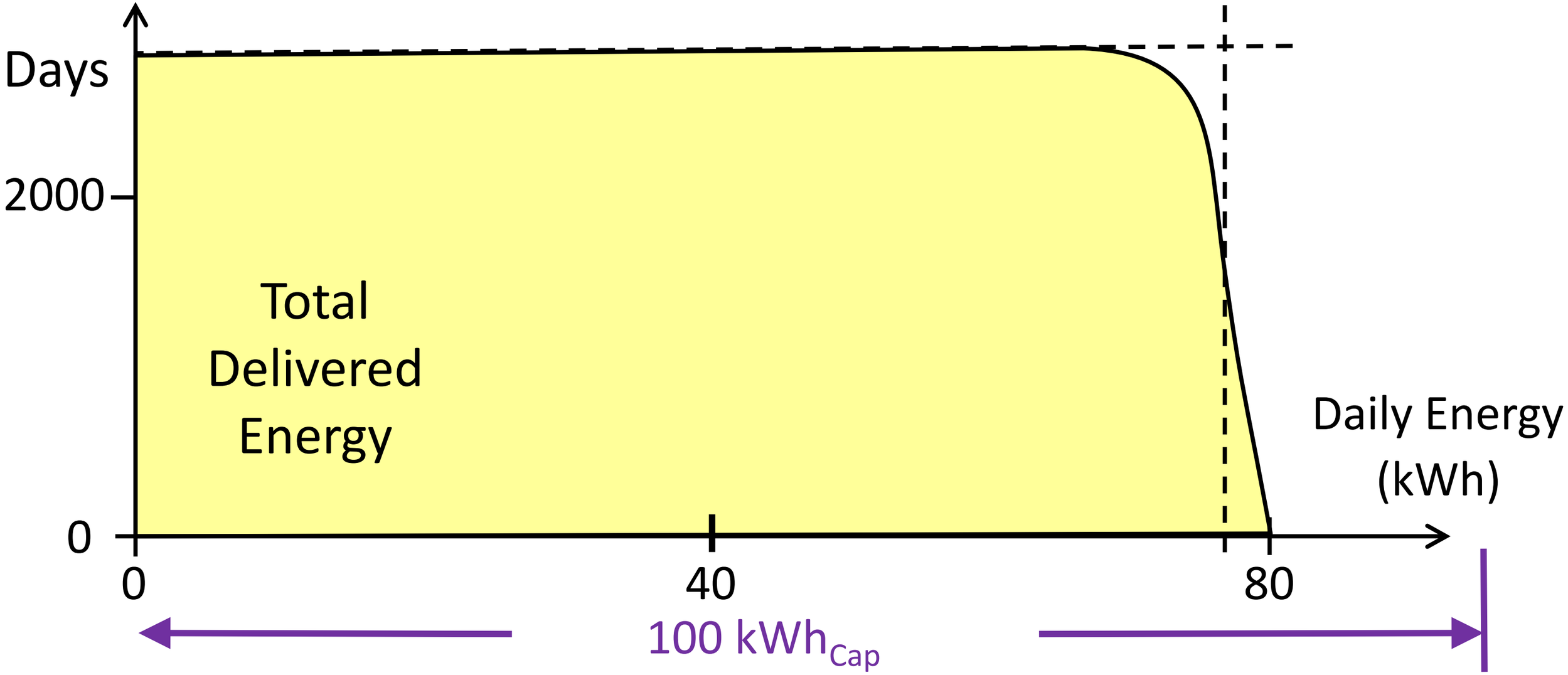
$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}} = \frac{2000 \times 75 \text{ kWh}}{100 \text{ kWh}} = 1500 \text{ EFC}$$



What can reduce the battery cost per kWh?



$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}} = \frac{3000 \times 75 \text{ kWh}}{100 \text{ kWh}} = 2250 \text{ EFC}$$

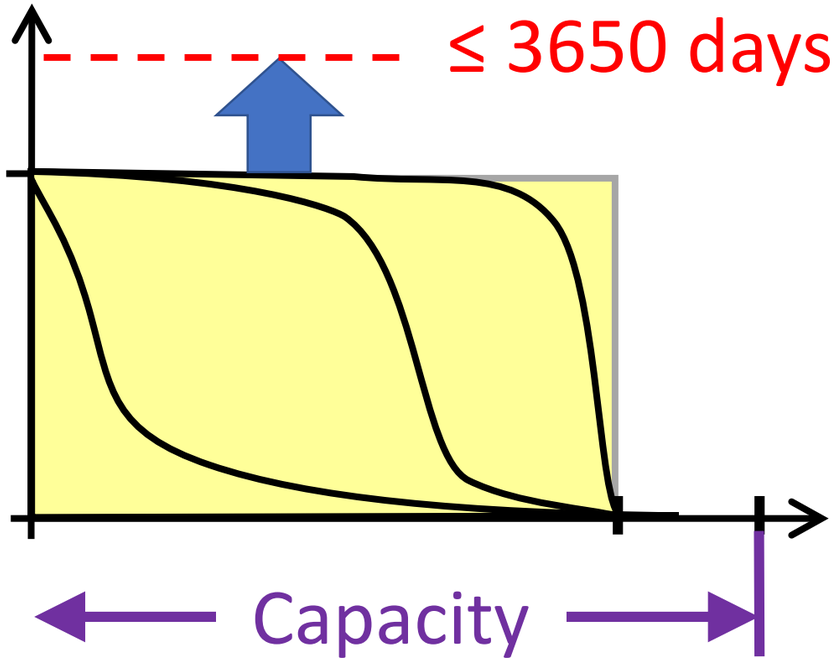


Summary: Night Charging Only

High Battery utilization is key for low cost.

- High Energy-to-Capacity ratio
- Many days

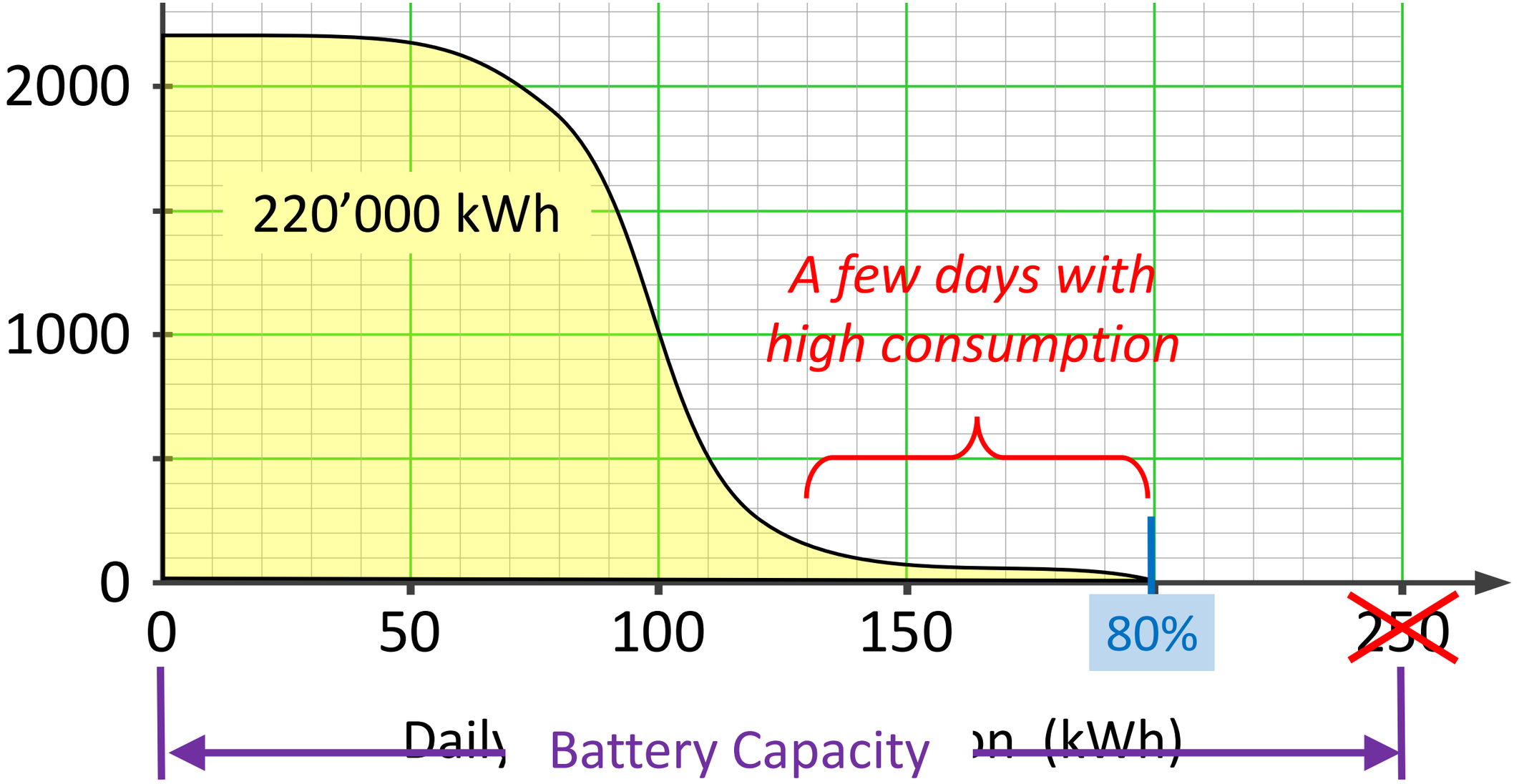
0% 15% **50%** 75% 80%



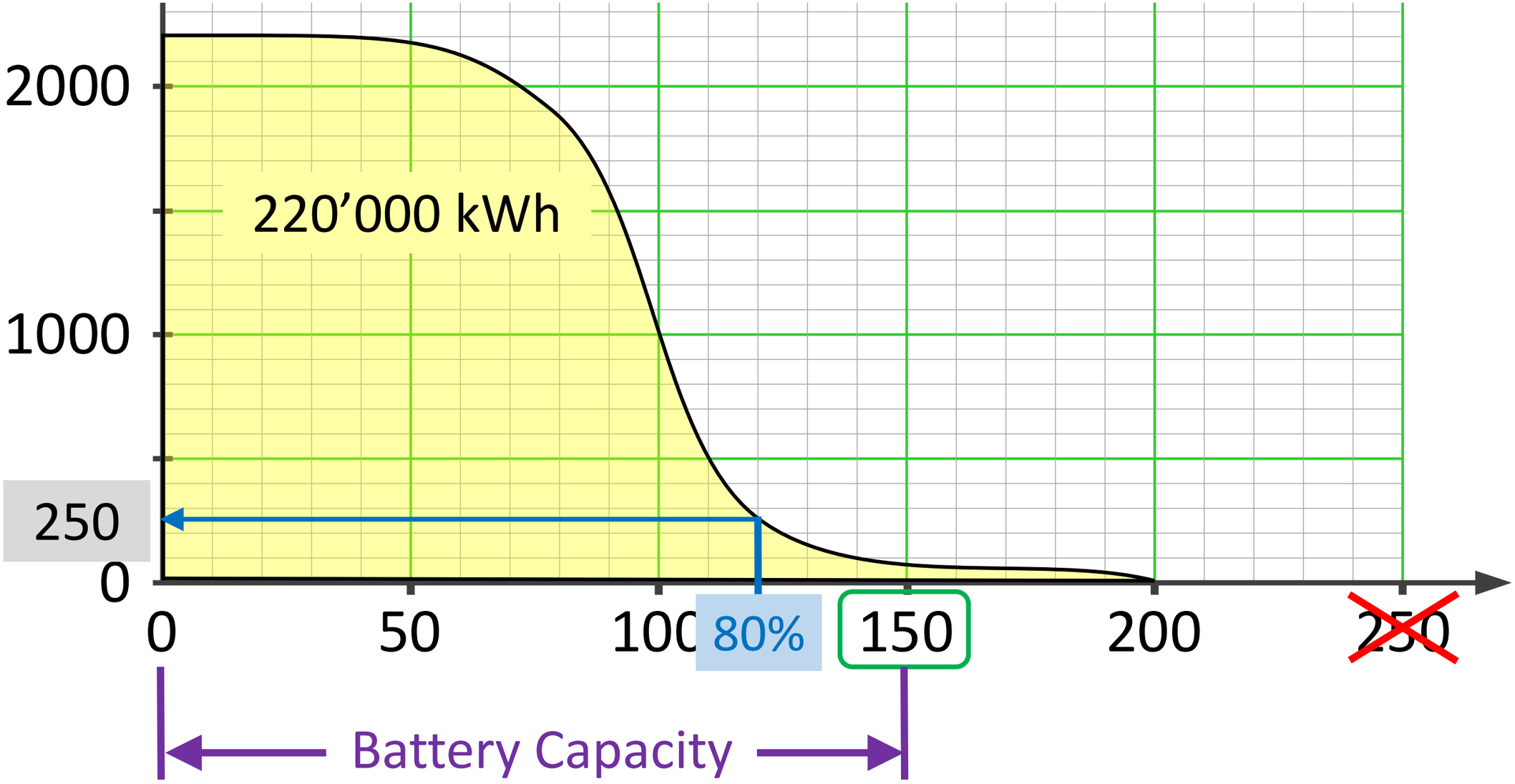
How to deal with

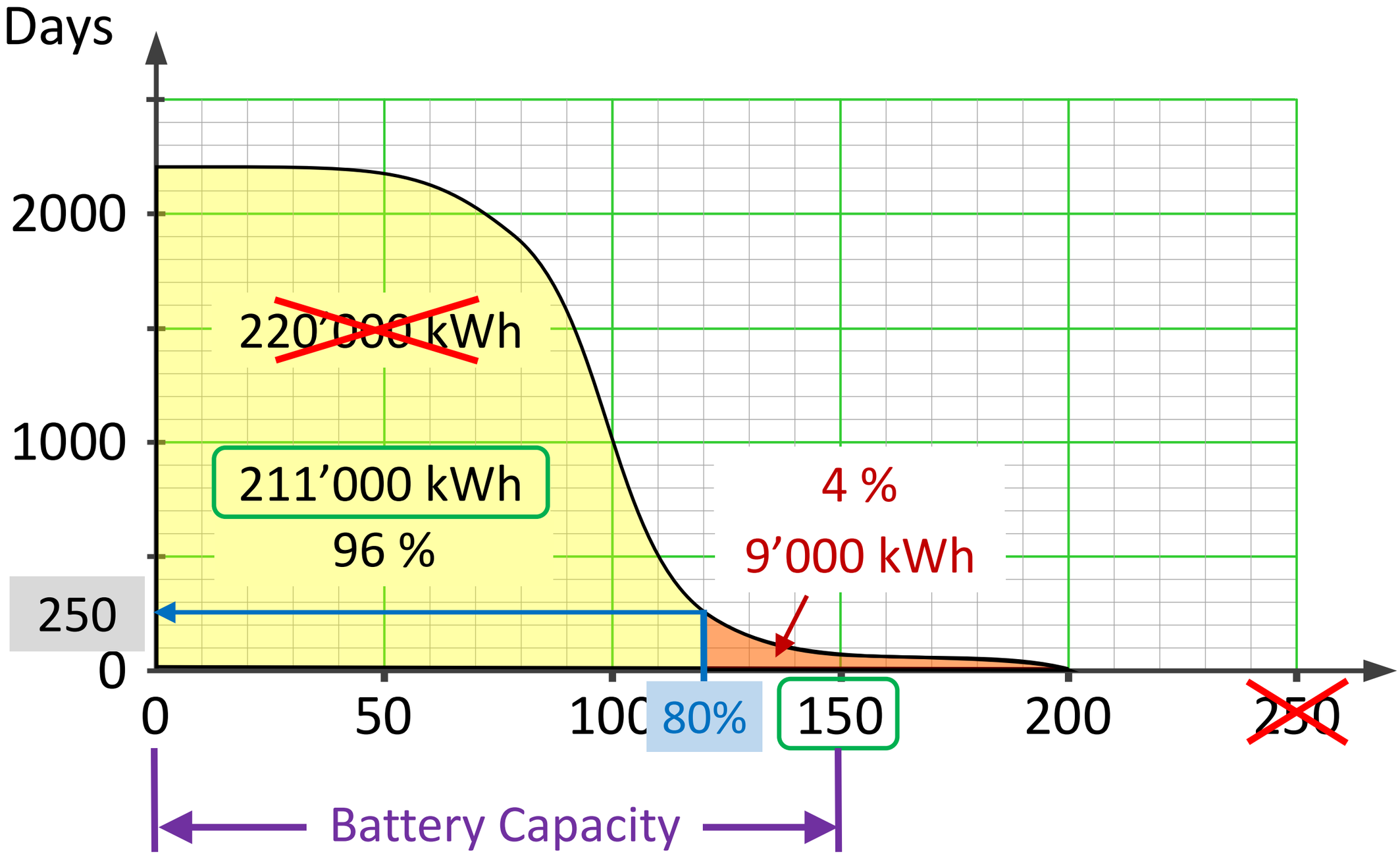
a few days with high consumption?

$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}} = \frac{220'000\ \text{kWh}}{250\ \text{kWh}} = 880\ \text{EFC}$$



$$\text{Battery Utilization} = \frac{\text{Total Delivered Energy}}{\text{Battery Capacity}} = \frac{220'000\ \text{kWh}}{150\ \text{kWh}} = 1467\ \text{EFC}$$




Days
2000
1000
250
0
220’000 kWh
211’000 kWh
96 %
4 %
9’000 kWh
0
50
100
80%
150
200
250
Battery Capacity

-17’300 €

60’000

40’000

20’000

0

22’000 €

6045 kWh

50 000 €

21’100 €

6045 kWh

30 000 €

Only Night Chg

Night & Fast Chg

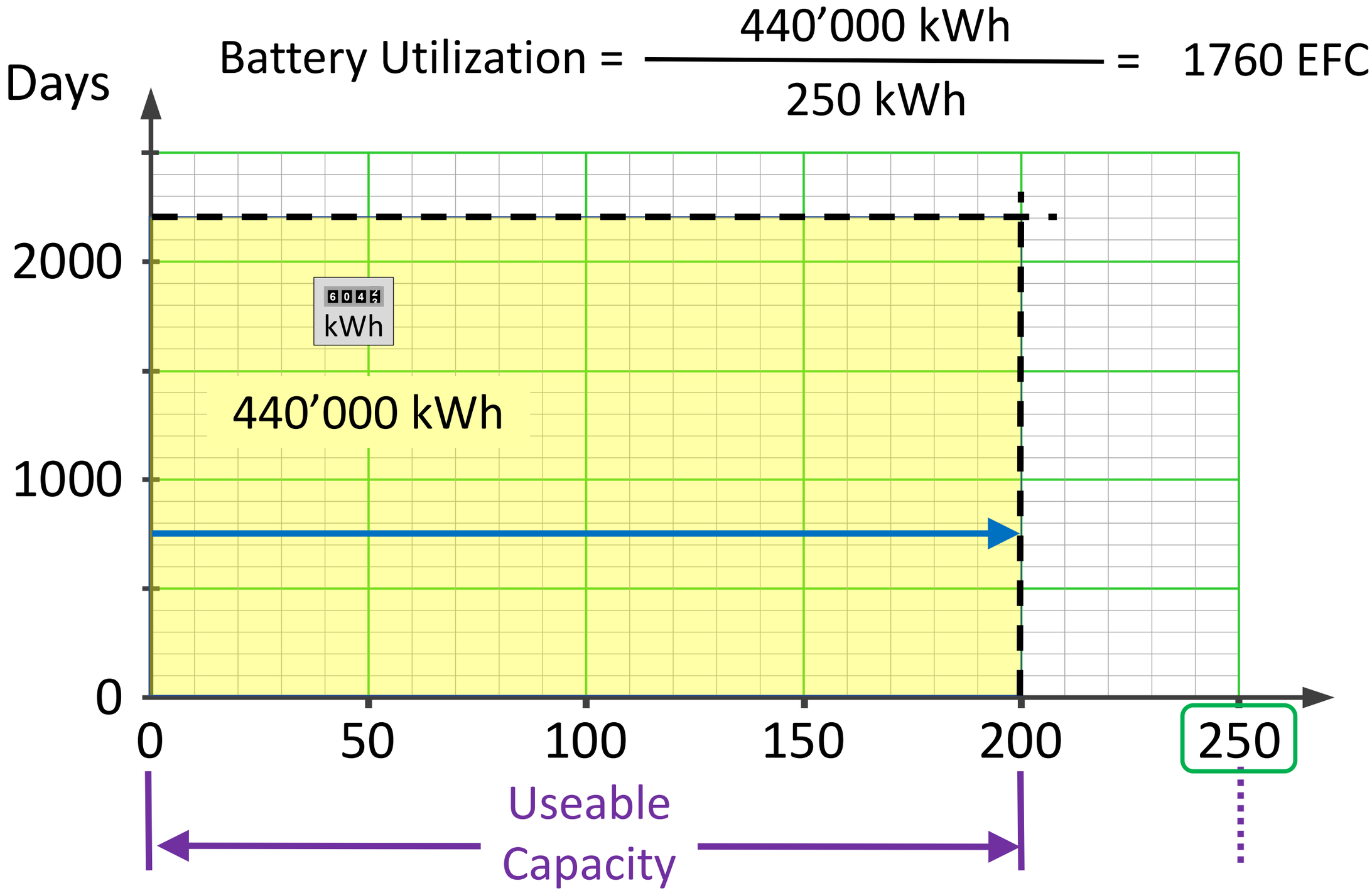
800 €

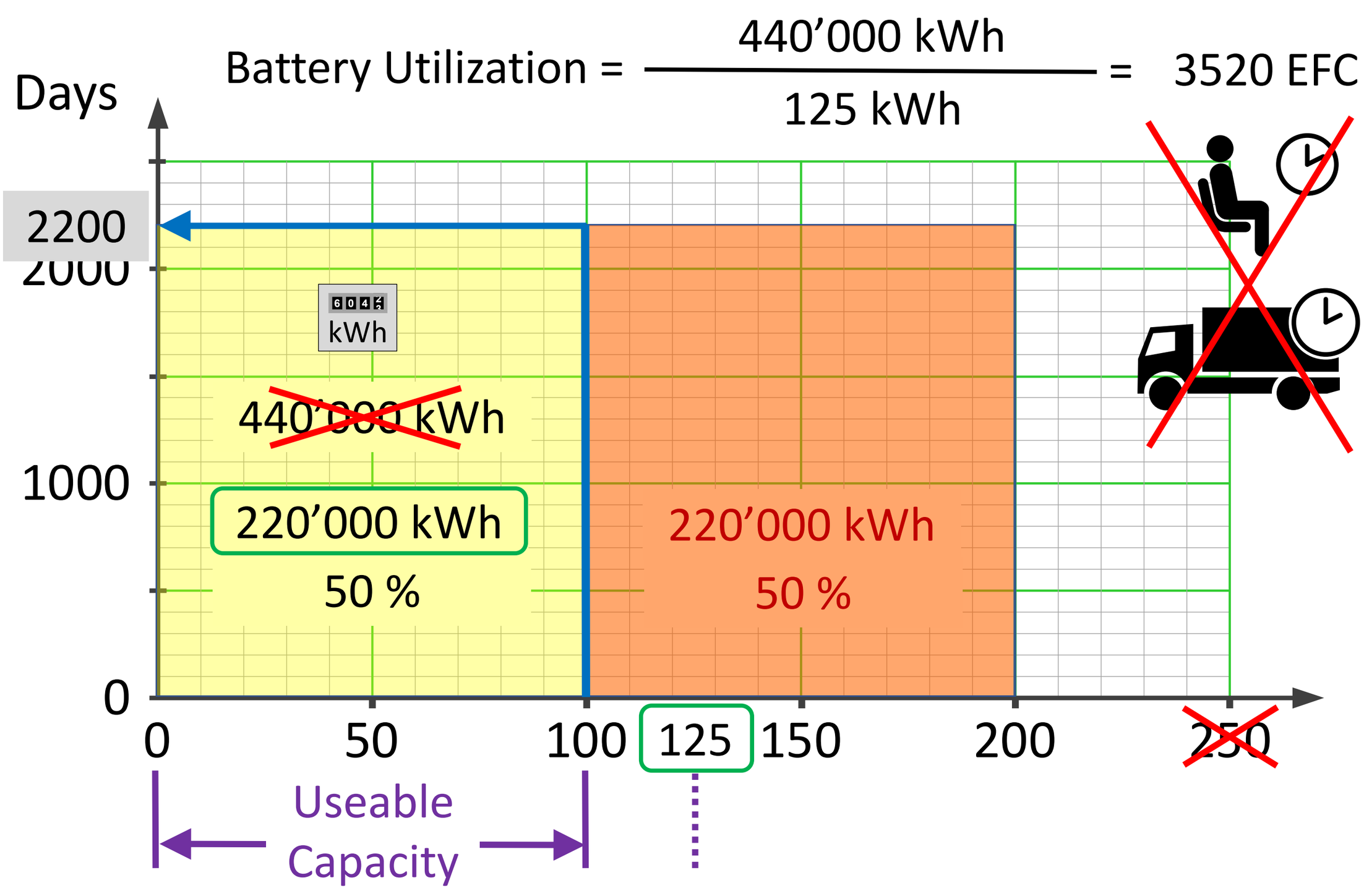
2’400 €

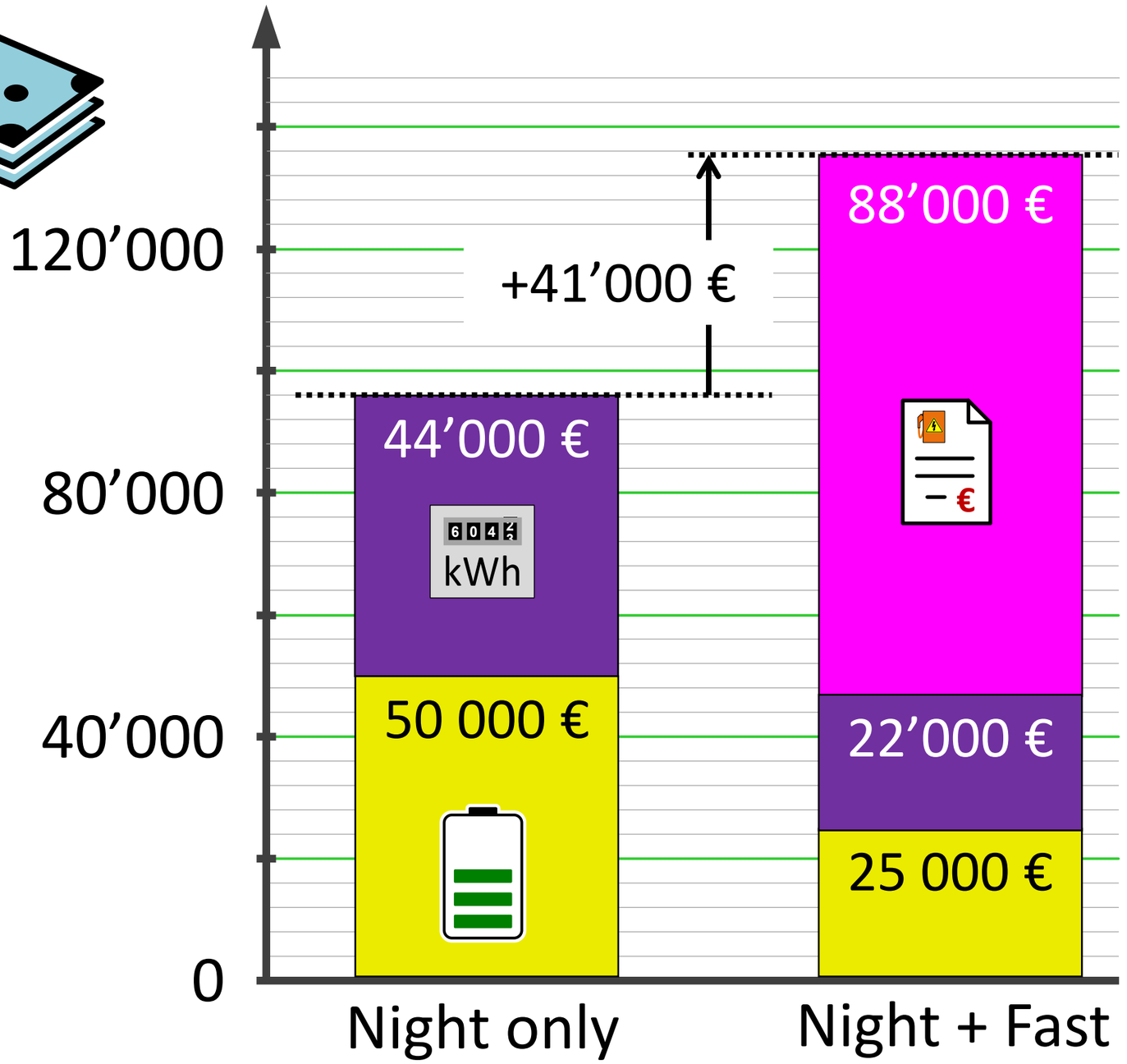
3’600 €

Fast Charger Good
Despite high price/kWh

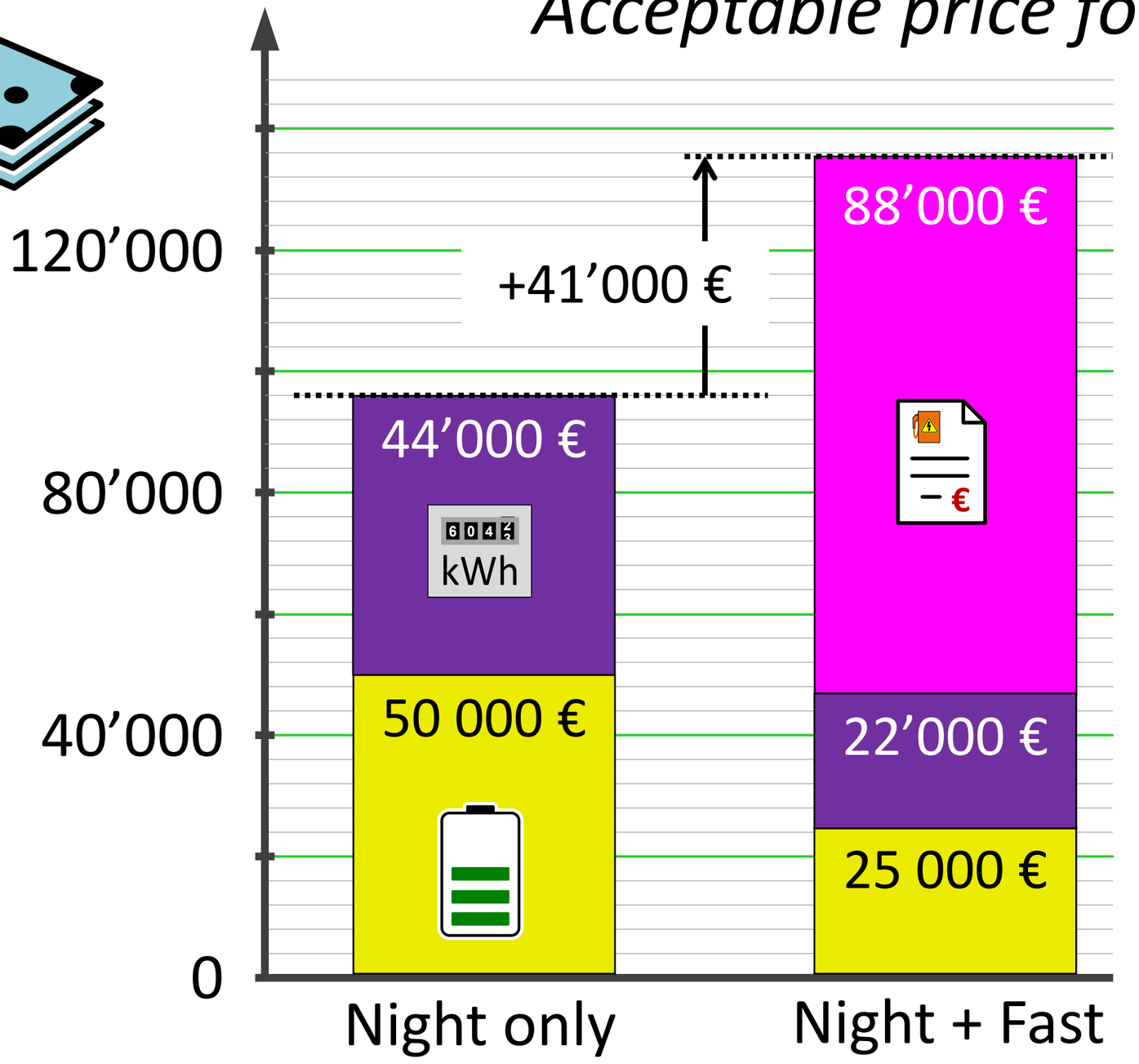
Fast charging every day


Battery Utilization = 440’000 kWh / 250 kWh = 1760 EFC
Days
2000
1000
0
6045
kWh
440’000 kWh
0
50
100
150
200
250
Useable
Capacity


Battery Utilization = 440’000 kWh / 125 kWh = 3520 EFC
Days
2200
2000
1000
0
6045
kWh
440’000 kWh
220’000 kWh
50 %
220’000 kWh
50 %
0
50
100
125
150
200
250
Useable
Capacity

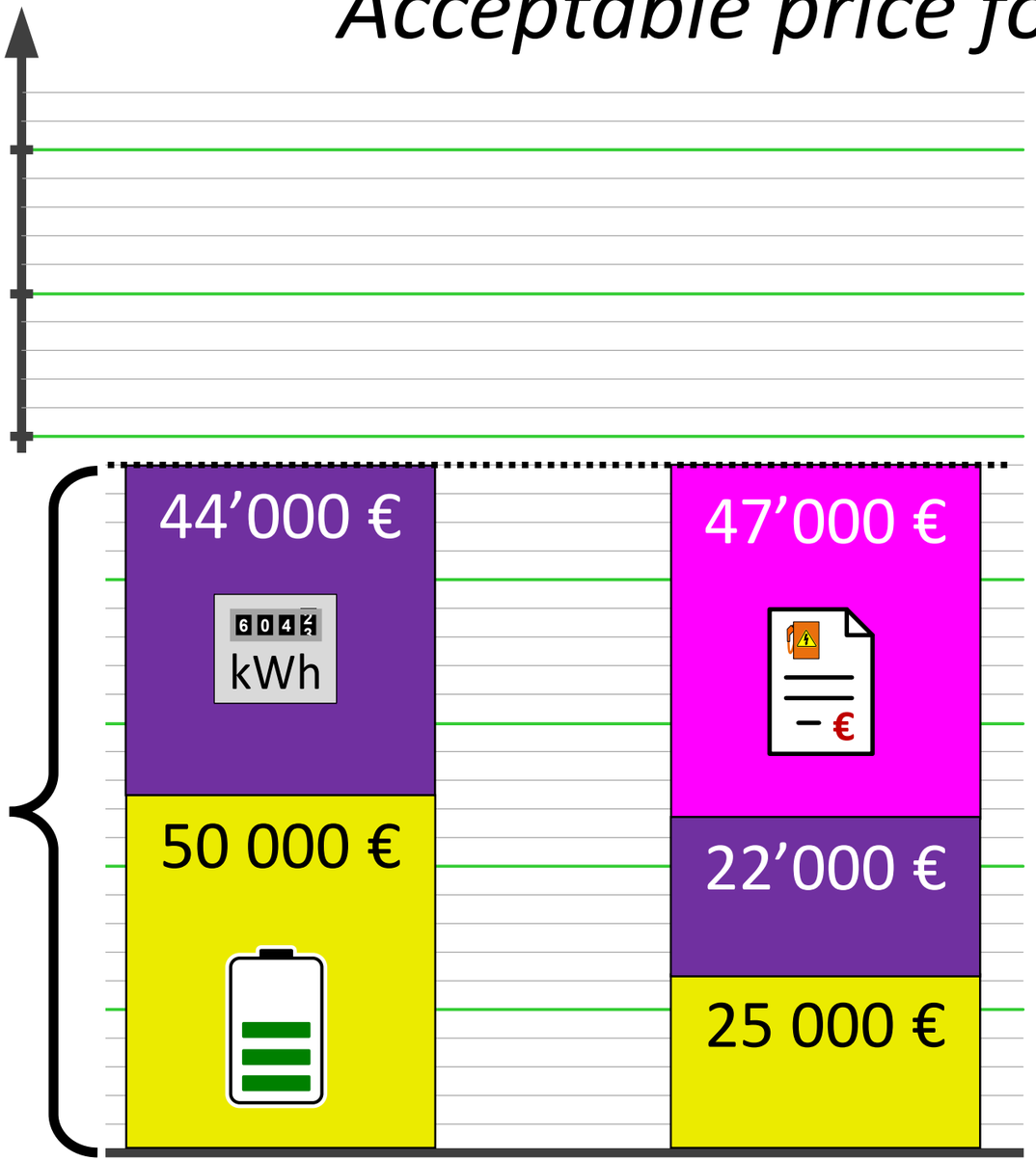

120’000
80’000
40’000
0
+41’000 €
44’000 €
6045
kWh
50 000 €
88’000 €
€
22’000 €
25 000 €
Night only
Night + Fast

Acceptable price for daily fast charging?



Acceptable price for daily fast charging?

120’000

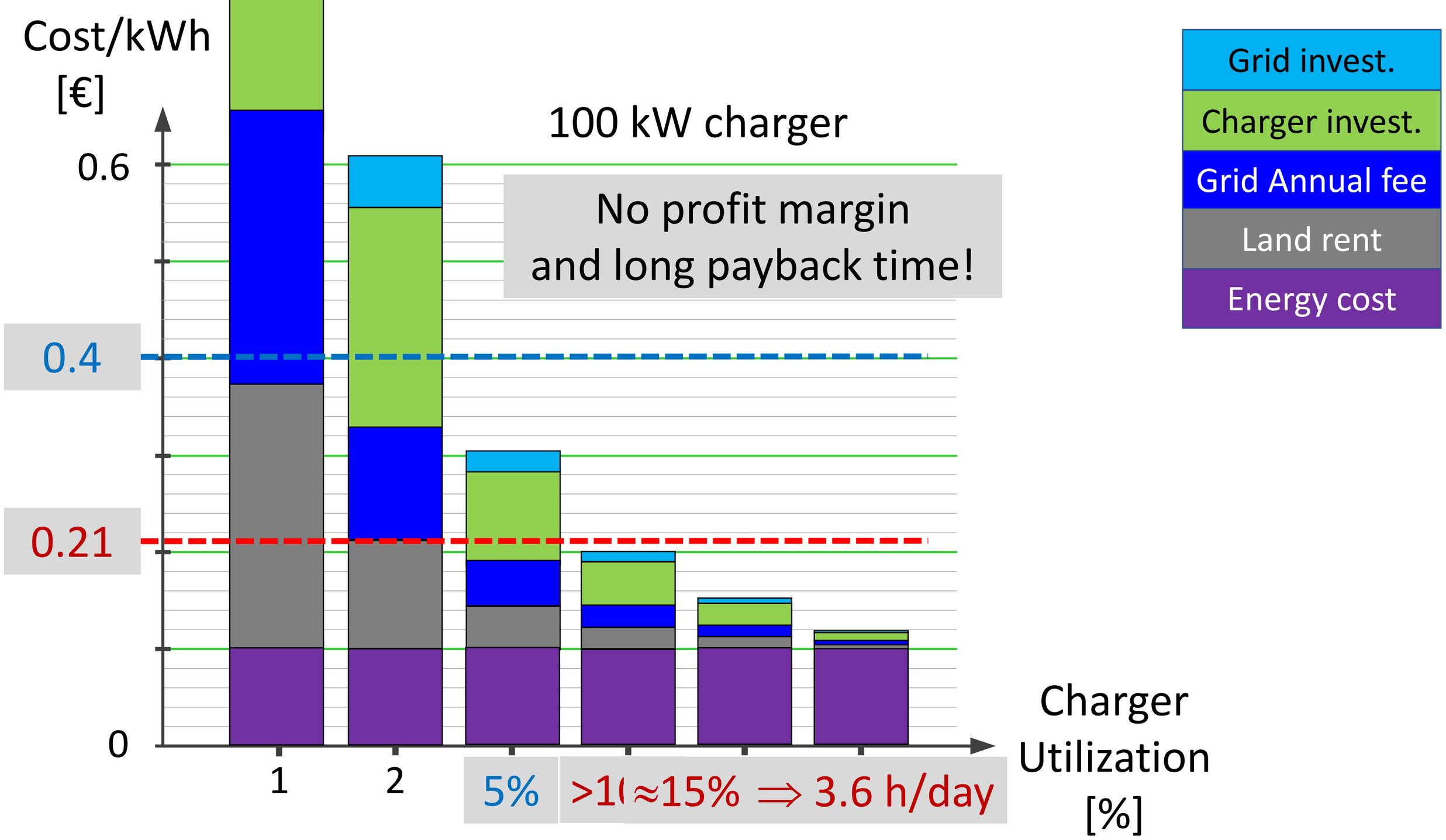


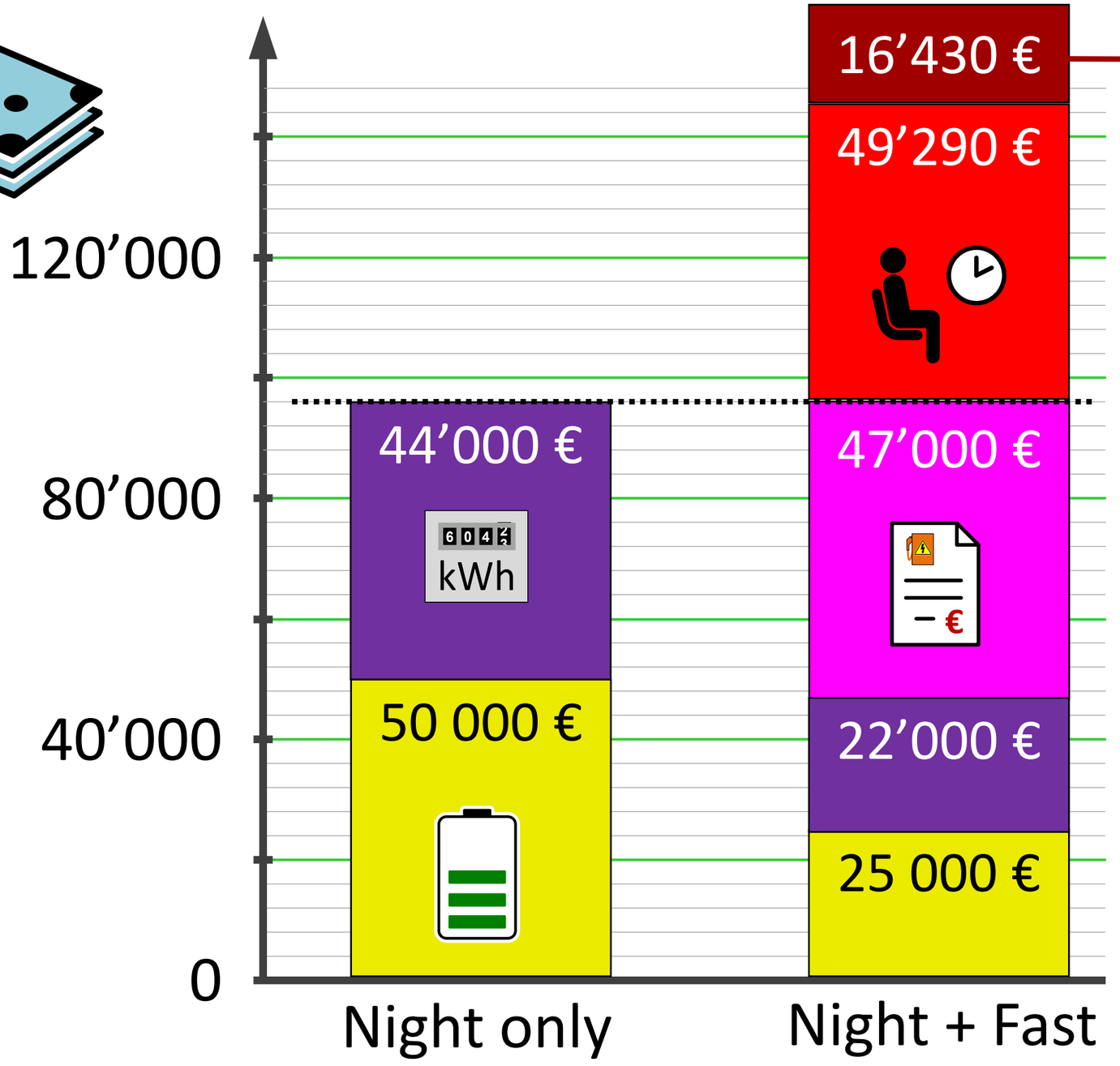
$$\frac{94'000\ €}{440'000\ kWh} =$$

= 0.21 €/kWh

$$\frac{47'000\ €}{220'000\ kWh} =$$

= 0.21 €/kWh


Cost/kWh
[€]
0.6
0.4
0.21
0
100 kW charger
No profit margin
and long payback time!
1
2
5%
>1(
≈15% ⇒ 3.6 h/day
Charger
Utilization
[%]
Grid invest.
Charger invest.
Grid Annual fee
Land rent
Energy cost



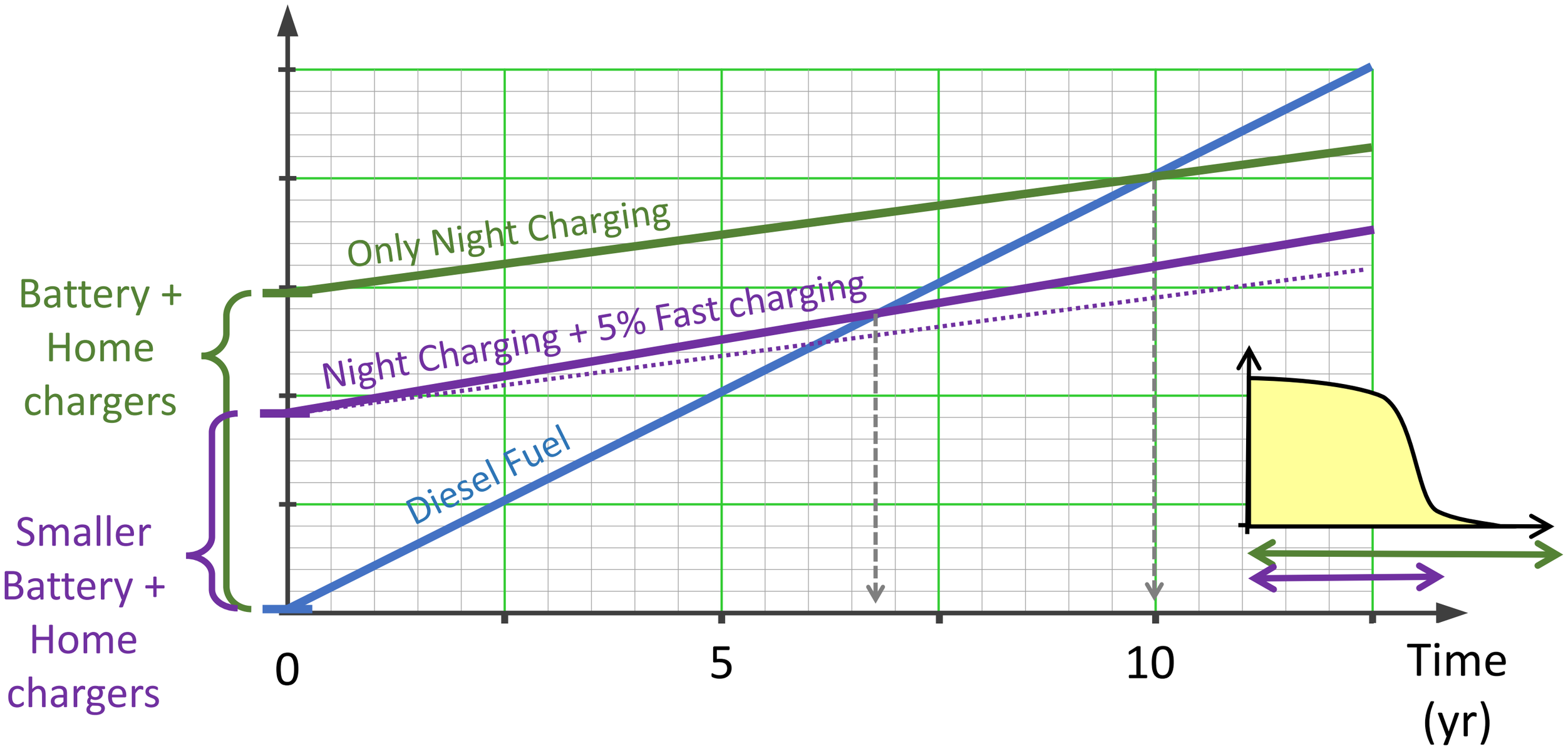
Indirect costs make daily fast charging very expensive?

(…but much less if charger power ≥ 1 MW)

High investment
and long break even time

Economic risk?

Total Cost – Powertrain + charger + “fuel”



Summary
Electric trucks

Cost Effective Battery Trucks

Not used daily, or
very varying driving distance

High Battery Cost!

Local Distribution

Night Charge + some Fast Chg

Regional Distribution
up to 300 km

Night Charge + some Fast Chg

Long Haul, varying route

Night Charge + much Fast Chg

Long Haul, Fixed route

Night Charge + much Fast Chg (own)

Insights about battery vehicles

- Using battery much leads to low cost:
  Many days & Similar consumption most days
- High consumption few days ⇒ Fast charging
- Long range not expensive – Weight *sometimes* an issue

Technology and Economy rather well known –
We need to find best solution for different hauliers needs.

Summary Vehicles

Battery utilization determines battery cost/kWh

- Use many days and similar energy consumption most days
- Fast charging can deal with a few days of high consumption
- Long driving range not expensive (if it is used daily)

Fast charging cost effective for a few days of high consumption

Daily fast charging: (Long haul)

- Low fast charging price necessary, and driver should not wait
- More complex to get low cost AND high availability