



INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION



Gearing up for lower cost electric drives: Accelerating the development of optimal electrified powertrains

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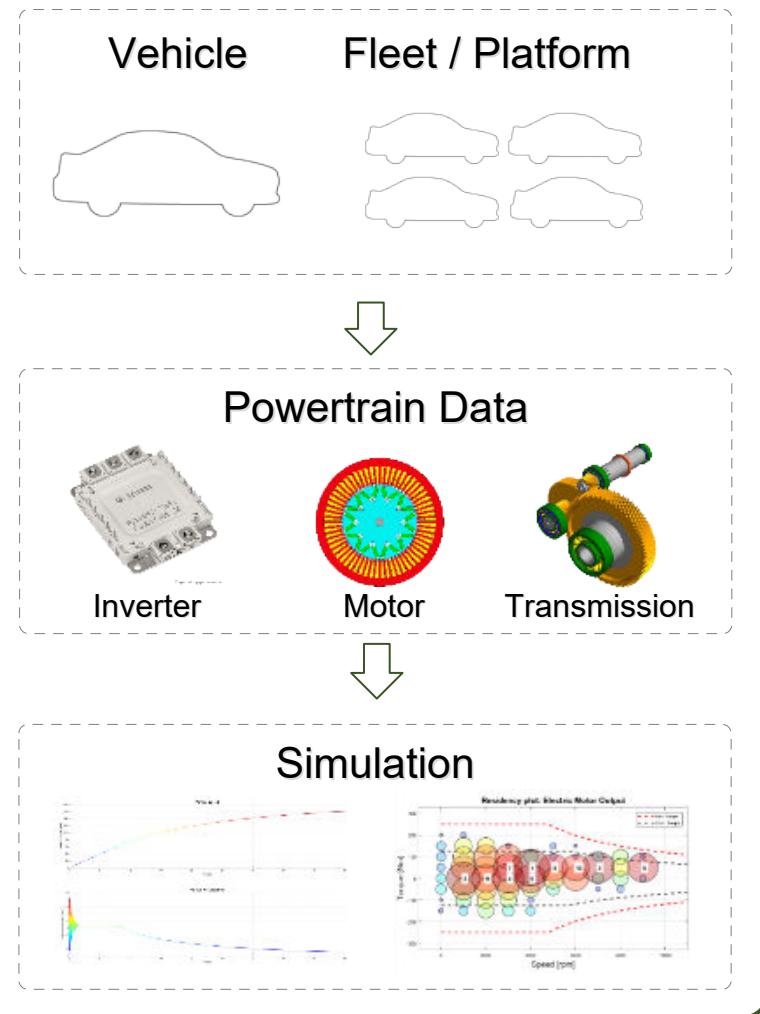
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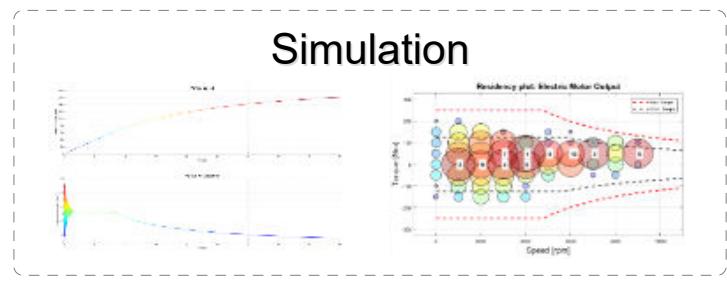
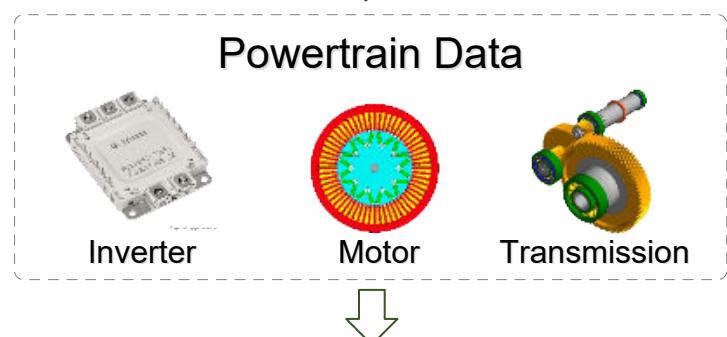
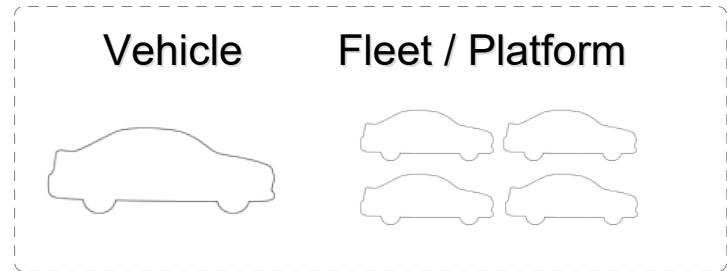
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Current Process



Current Process



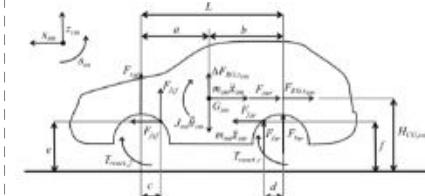
Suppliers



- Limited scope
- Time consuming
 - Costs?
 - Accuracy?
 - Non-flexible

Powertrain Data Sources

Simulation



- Long lead time
- Expensive software
- Expensive engineers
- Limited design space

Hardware



- Very expensive
- Test bed time
- Long lead time
- One-off
- The right option?



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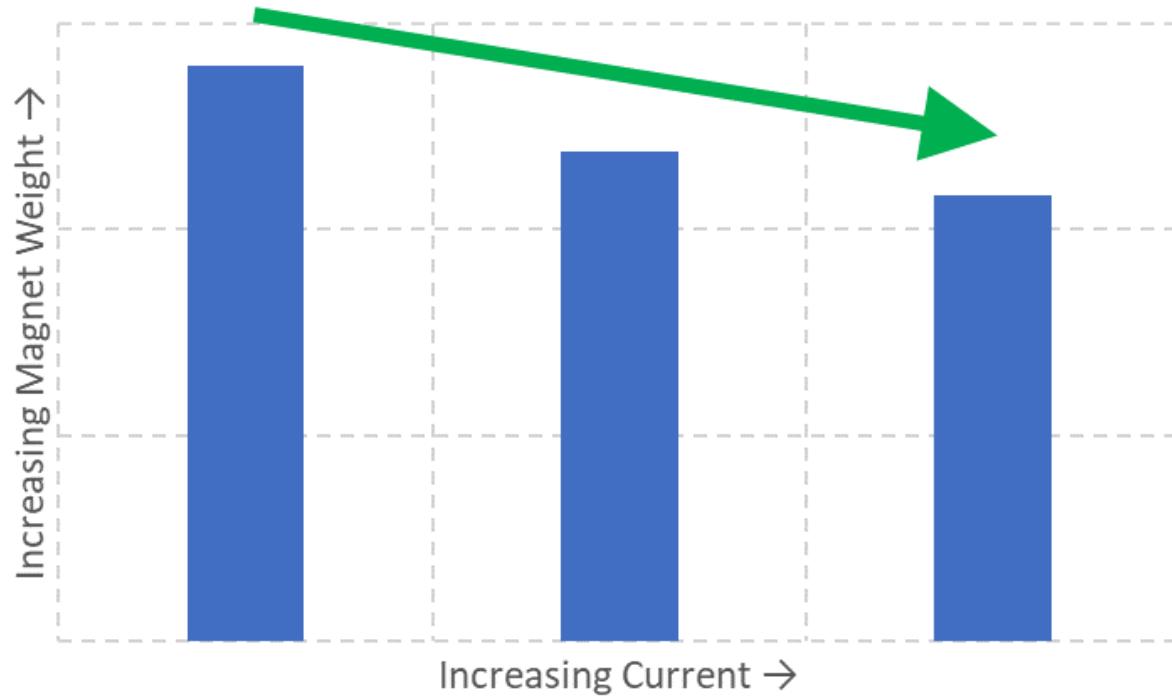
Reducing Motor Cost



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Reducing Motor Cost



Reducing Motor Cost

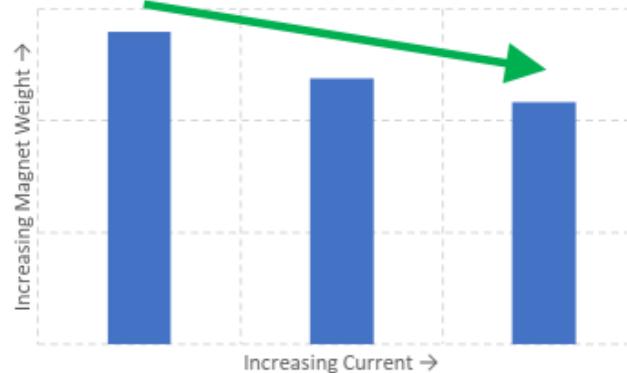
Motor



Reduced magnet mass



Reduced cost



Reducing Motor Cost

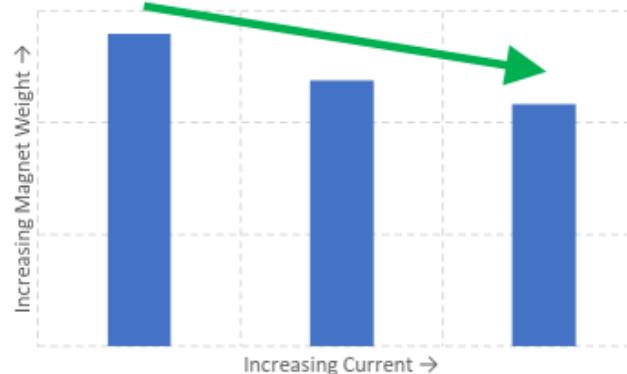
Motor



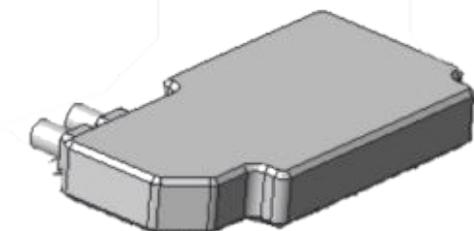
Reduced magnet mass



Reduced cost



Inverter



Increased cost



Reduced efficiency





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Customer Targets

Efficiency?

Cost?

Mass?

Trade-offs



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Customer Targets

Efficiency?
Cost?
Mass?

Trade-offs

Vehicle / Powertrain Requirements

What is the vehicle performance?

What is the vehicle range?

How much does the powertrain cost?





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ePOP: electric Powertrain Optimisation Process



Vehicle / Powertrain Requirements

- What is the vehicle performance?
- What is the vehicle range?
- How much does the powertrain cost?



Powertrain Data

Inverter Data



Motor Data



- Losses
- Mass
- Inertia
- Cost

Transmission Data



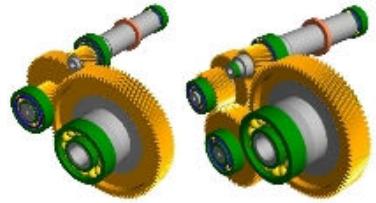


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Transmission Type

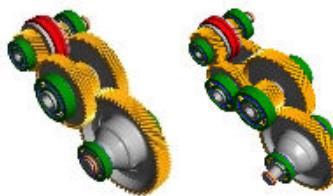
Parallel Shafts



Planetary Arrangements

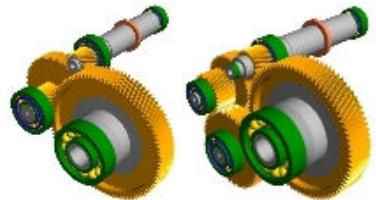


Multi Speeds



Transmission Type

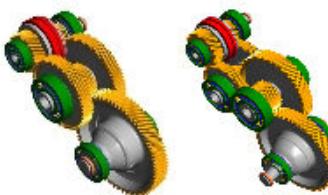
Parallel Shafts



Planetary Arrangements



Multi Speeds



Sources of Power Loss (Single Load Case)

Bearing Losses

Loaded

Un-Loaded

Mesh Losses

Churning Losses

Seal Losses

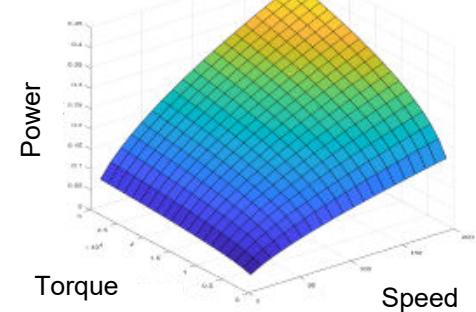
2-Stage Parallel Losses



3-Stage Parallel Losses

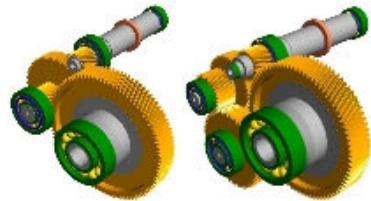


Efficiency Map



Transmission Type

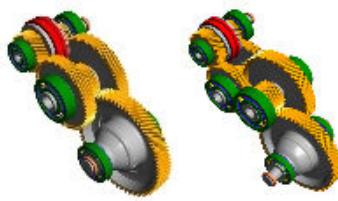
Parallel Shafts



Planetary Arrangements



Multi Speeds



Mass / Inertia

Shaft / Gears
Differential + Housing

Internals Mass = Steel

Case Mass = Aluminium

Sources of Power Loss (Single Load Case)

Bearing Losses

Loaded

Un-Loaded

Mesh Losses

Churning Losses

Seal Losses

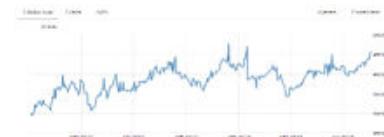
2-Stage Parallel Losses



3-Stage Parallel Losses

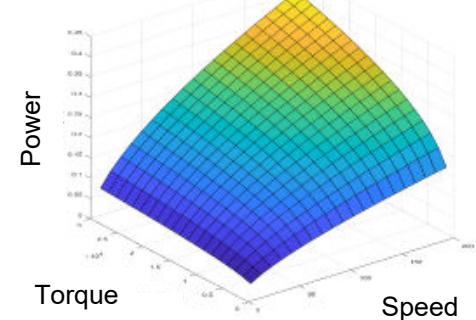


Cost



Steel (£/kg) / Aluminium (£/kg) / Actuator

Efficiency Map



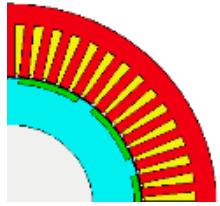


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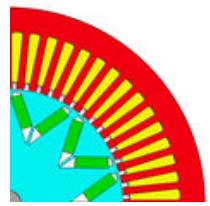


Electric Motor Type

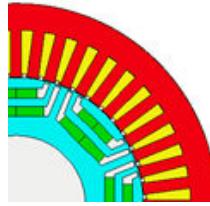
SPM



IPM (V)



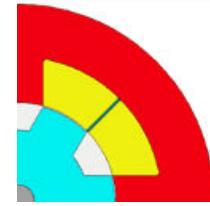
IPM (U)



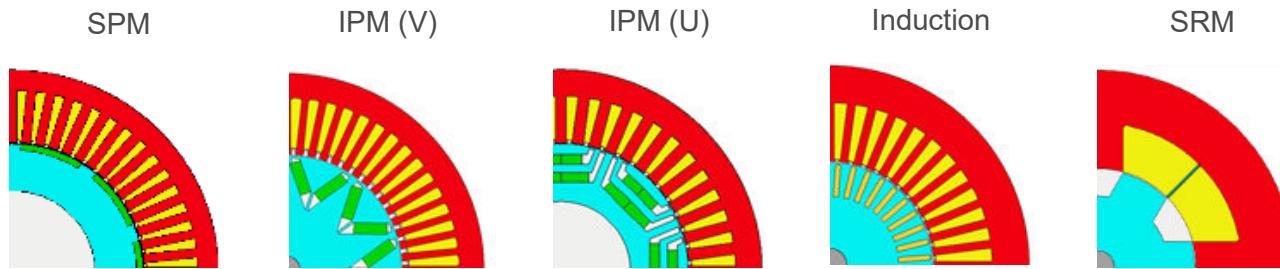
Induction



SRM



Electric Motor Type



Sources of Power Loss (Single Load Case)

Copper Losses

Iron Losses

Magnet Losses

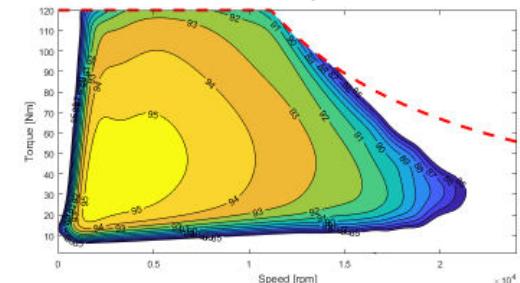
IPM (V) Losses



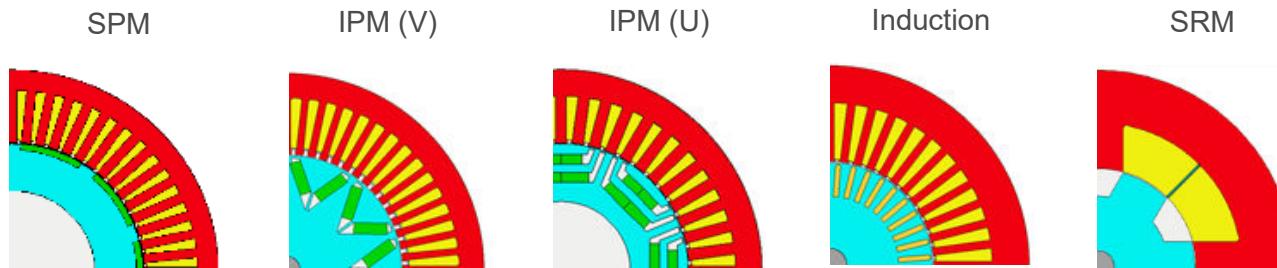
Induction Motor Losses



Efficiency Map



Electric Motor Type



Sources of Power Loss (Single Load Case)

Copper Losses

Iron Losses

Magnet Losses

IPM (V) Losses



Induction Motor Losses



Mass / Inertia

Copper Mass

Iron Mass

Magnet Mass

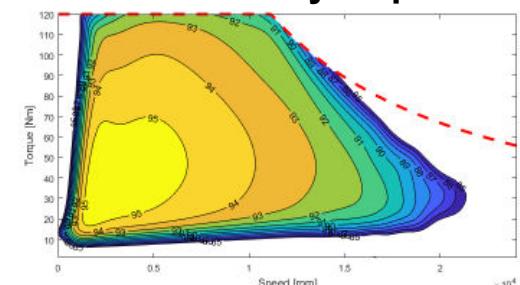
Cost

Copper = £ / kg

Iron = £ / kg

Magnet = £ / kg

Efficiency Map

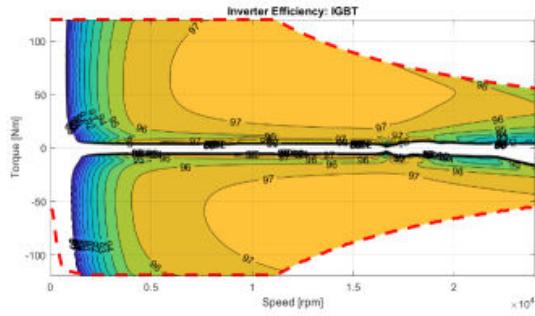




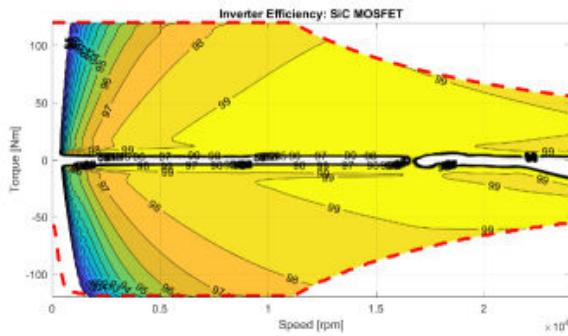
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Inverter Type



IGBT



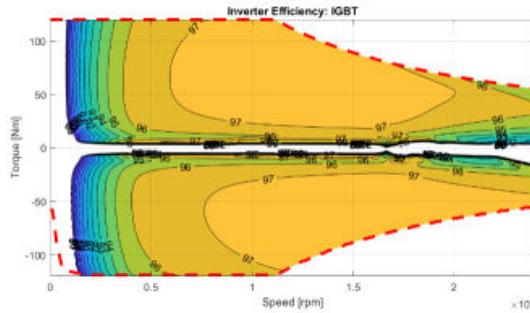
SiC



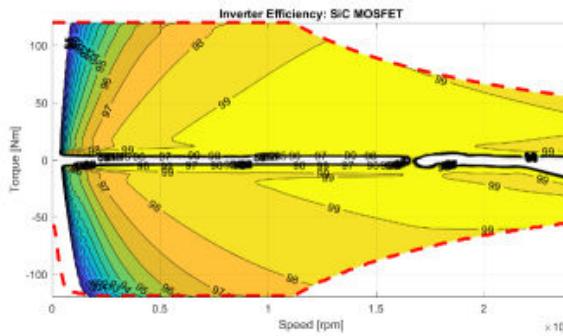
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Inverter Type



IGBT



SiC

Sources of Power Loss (Single Load Case)

Gate Switching Losses

Gate Conduction Losses

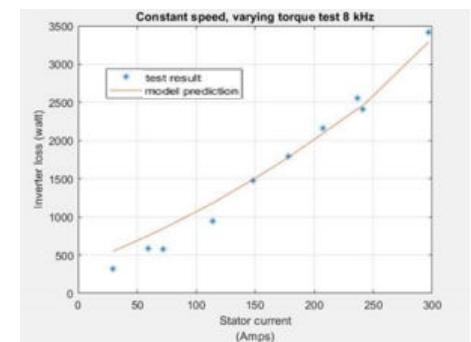
Diode Switching Losses

Diode Conduction Losses

IGBT Losses

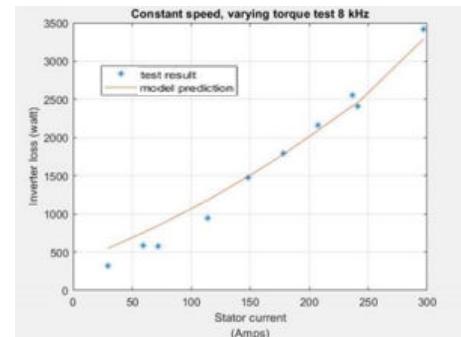
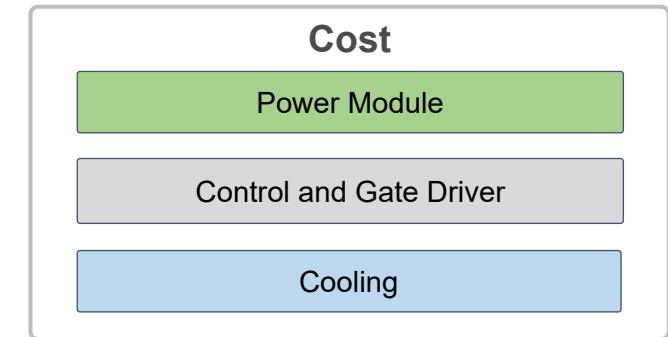
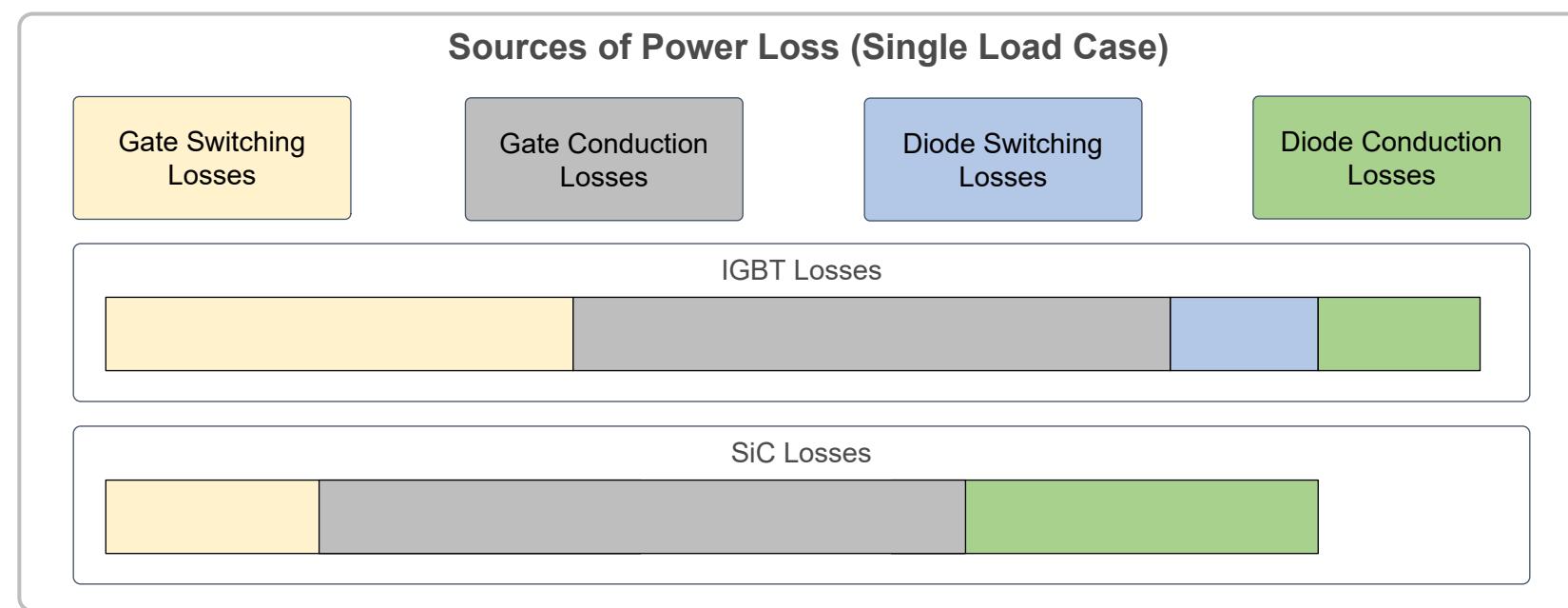
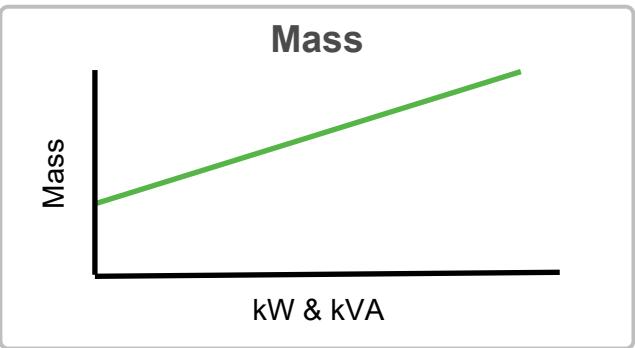
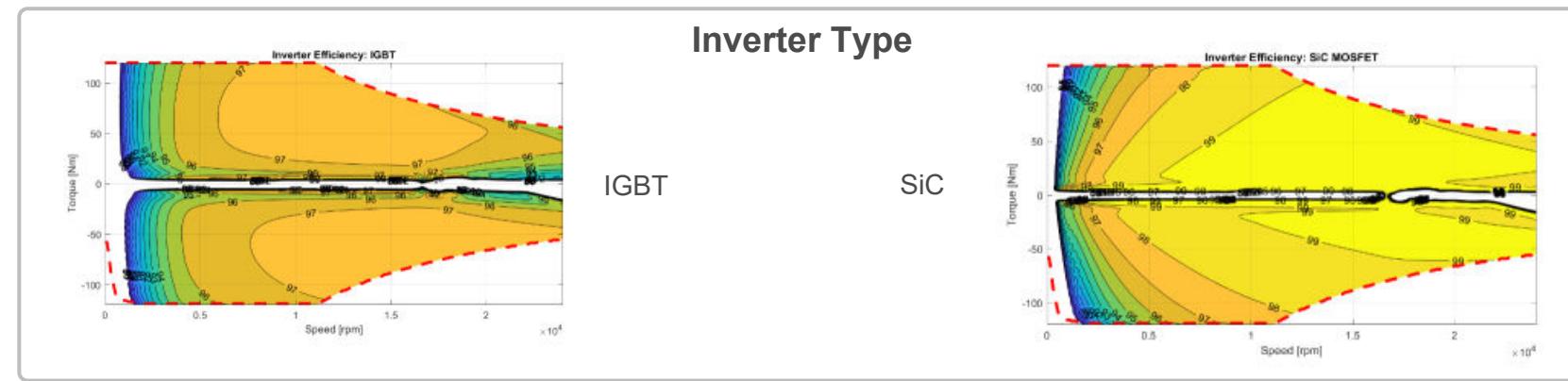


SiC Losses



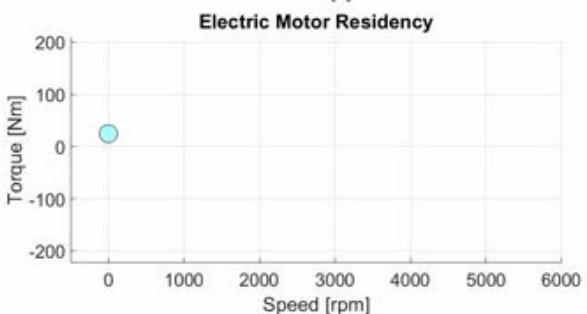
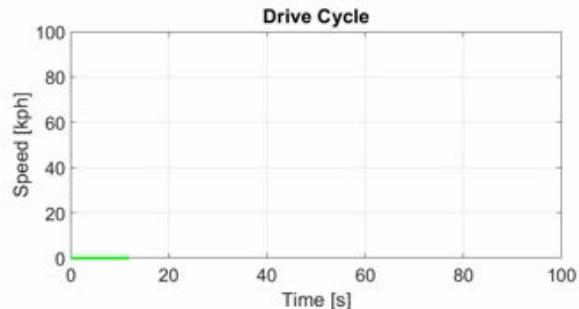
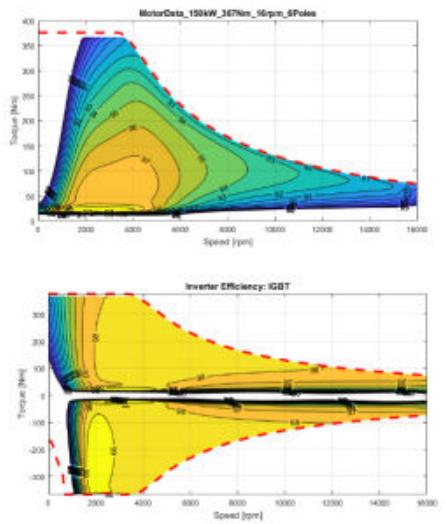


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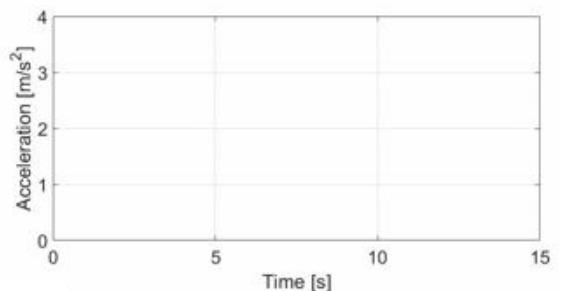
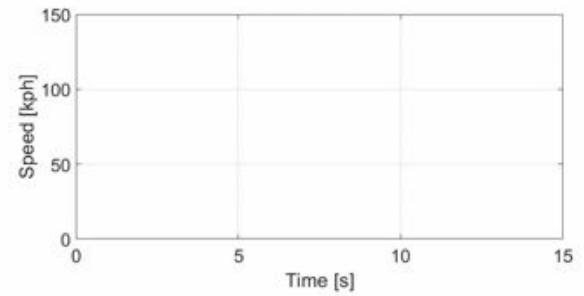
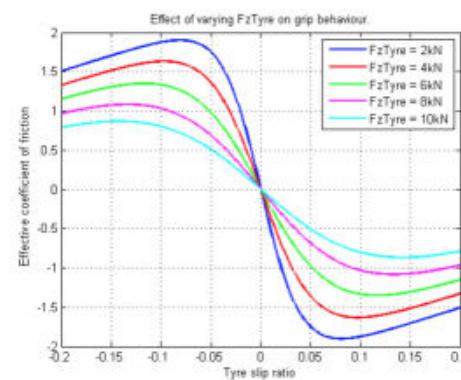
Drive Cycle Energy Prediction

What's the vehicles range?



Vehicle Performance Prediction

What's the top speed?
Acceleration times?





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Material



Mass



Manufacturing



$$Cost\ Function = \sum Cost_{Mat.} + Cost_{Mass.} + Cost_{Manu.} + Cost_{Pack.} + Cost_{Cool.} + Cost_{NVH}$$



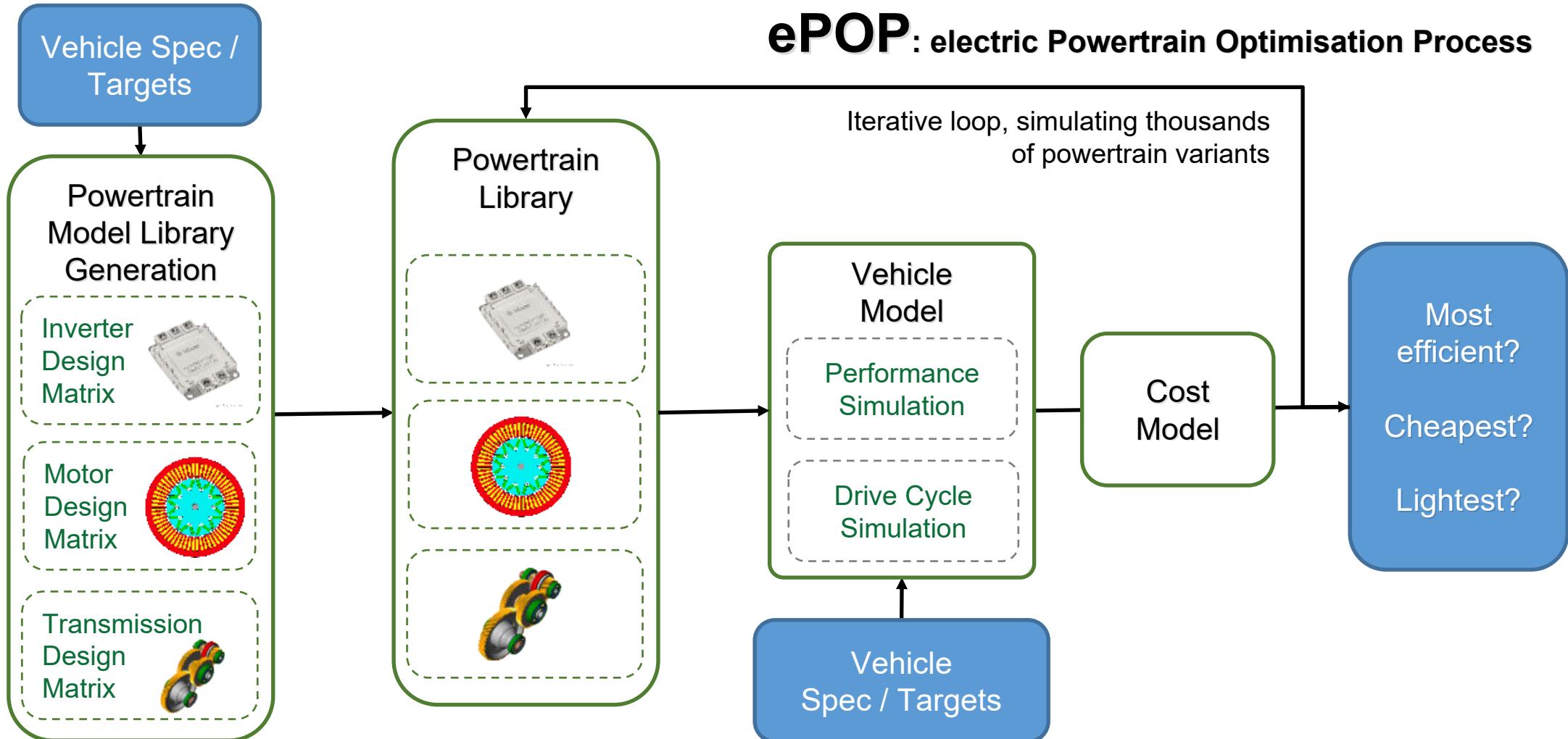
Packaging



Cooling

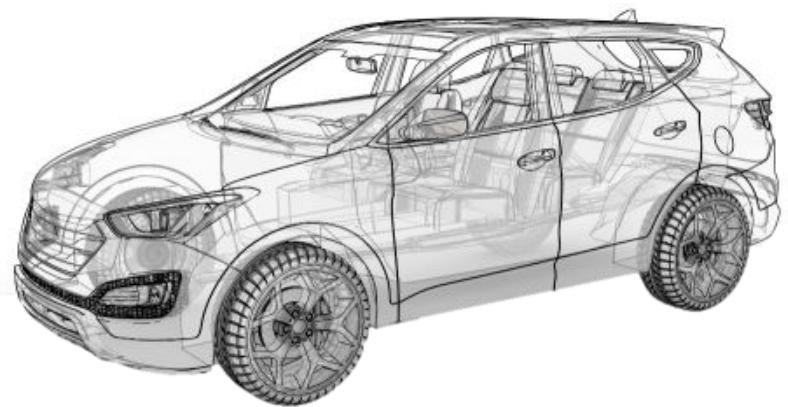


NVH



Case Study Vehicle Specification

Premium SUV
Pure EV



Performance Targets

Range
Top Speed
Acceleration

Transmission Variants

Single speed	2-speeds
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Motor Variants

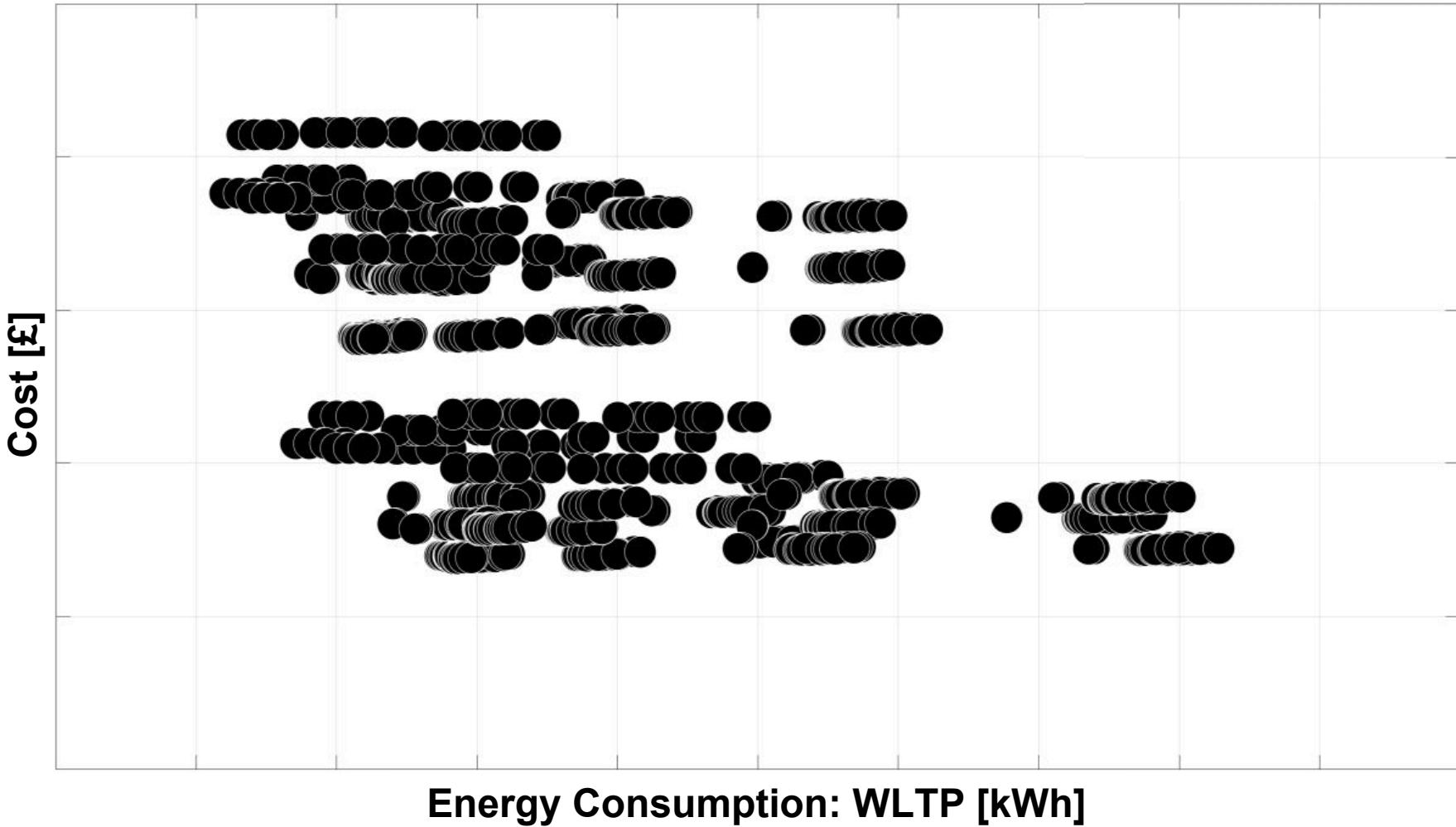
160 kW Fixed (V shape, U shape)	350, 400, 450 A
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Inverter Variants

IGBT	SiC MOSFET
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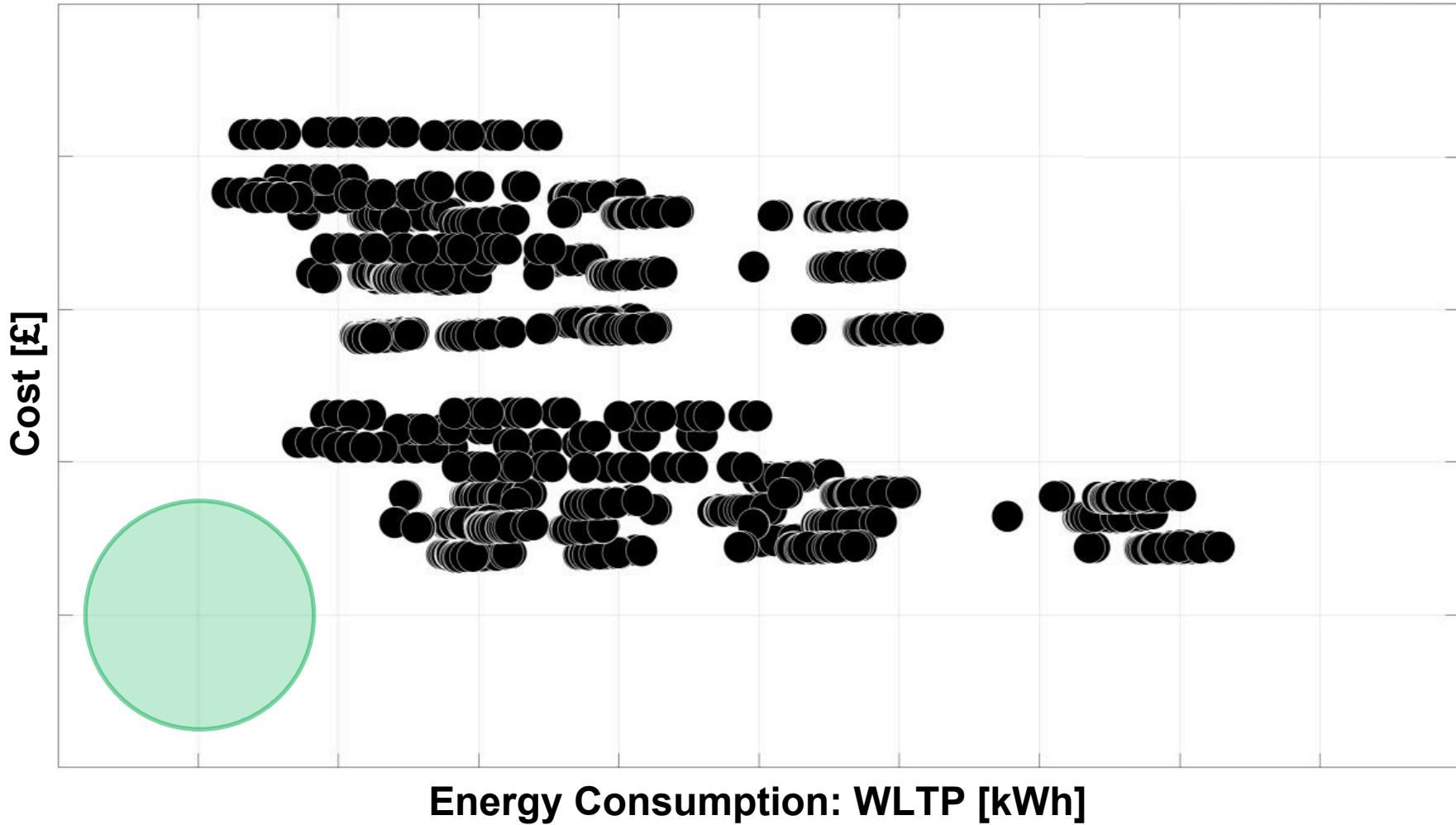


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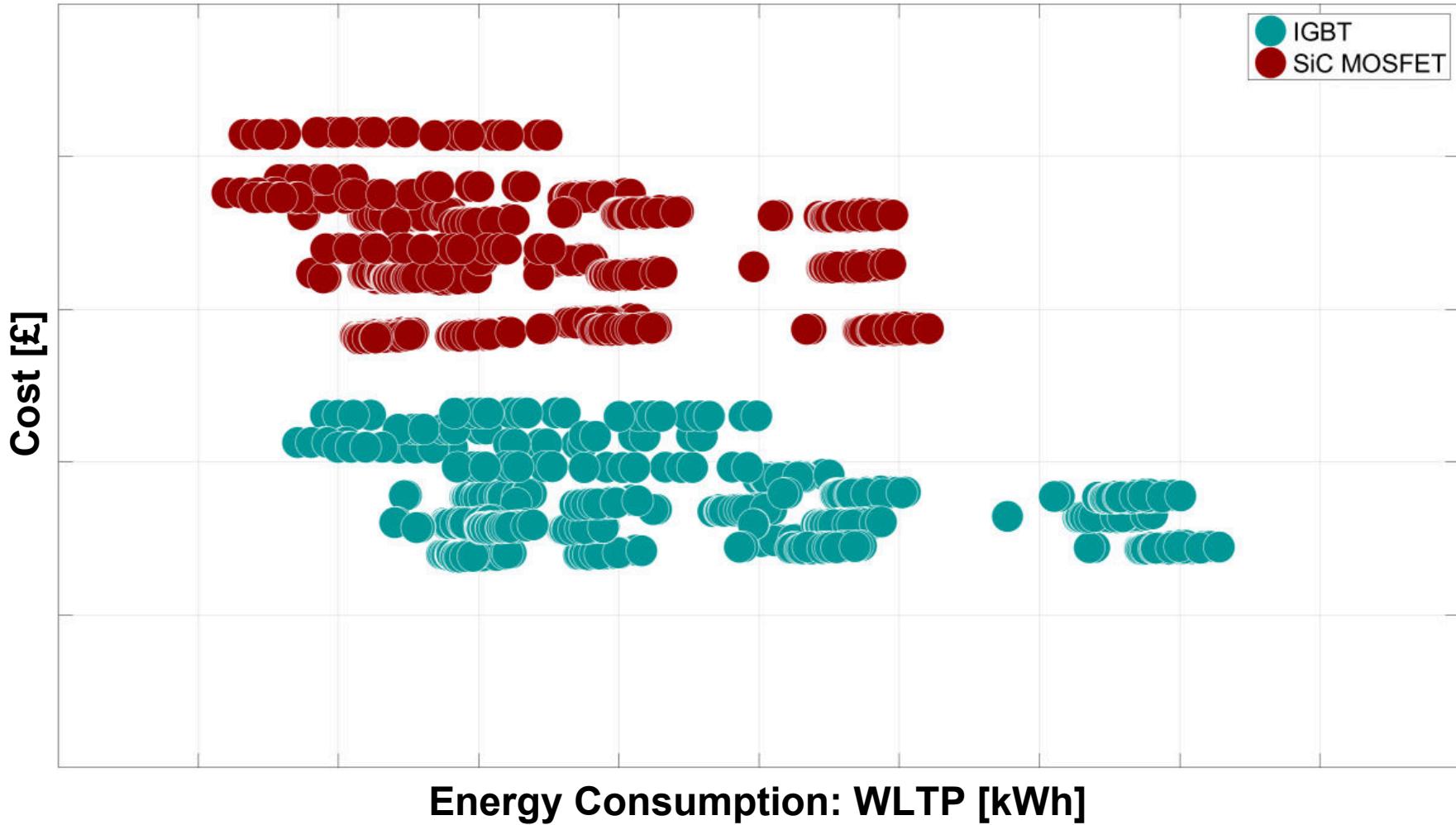


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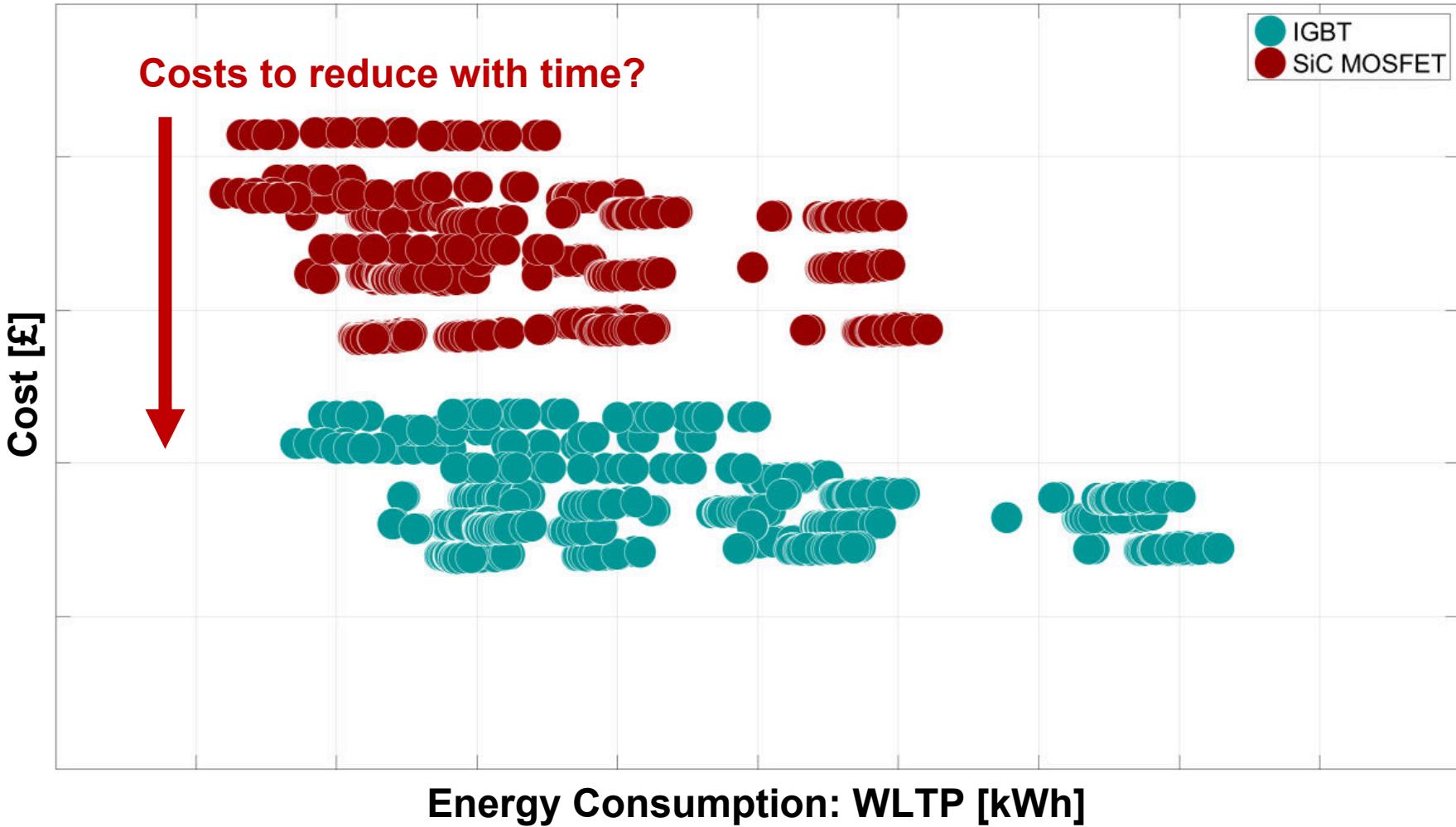


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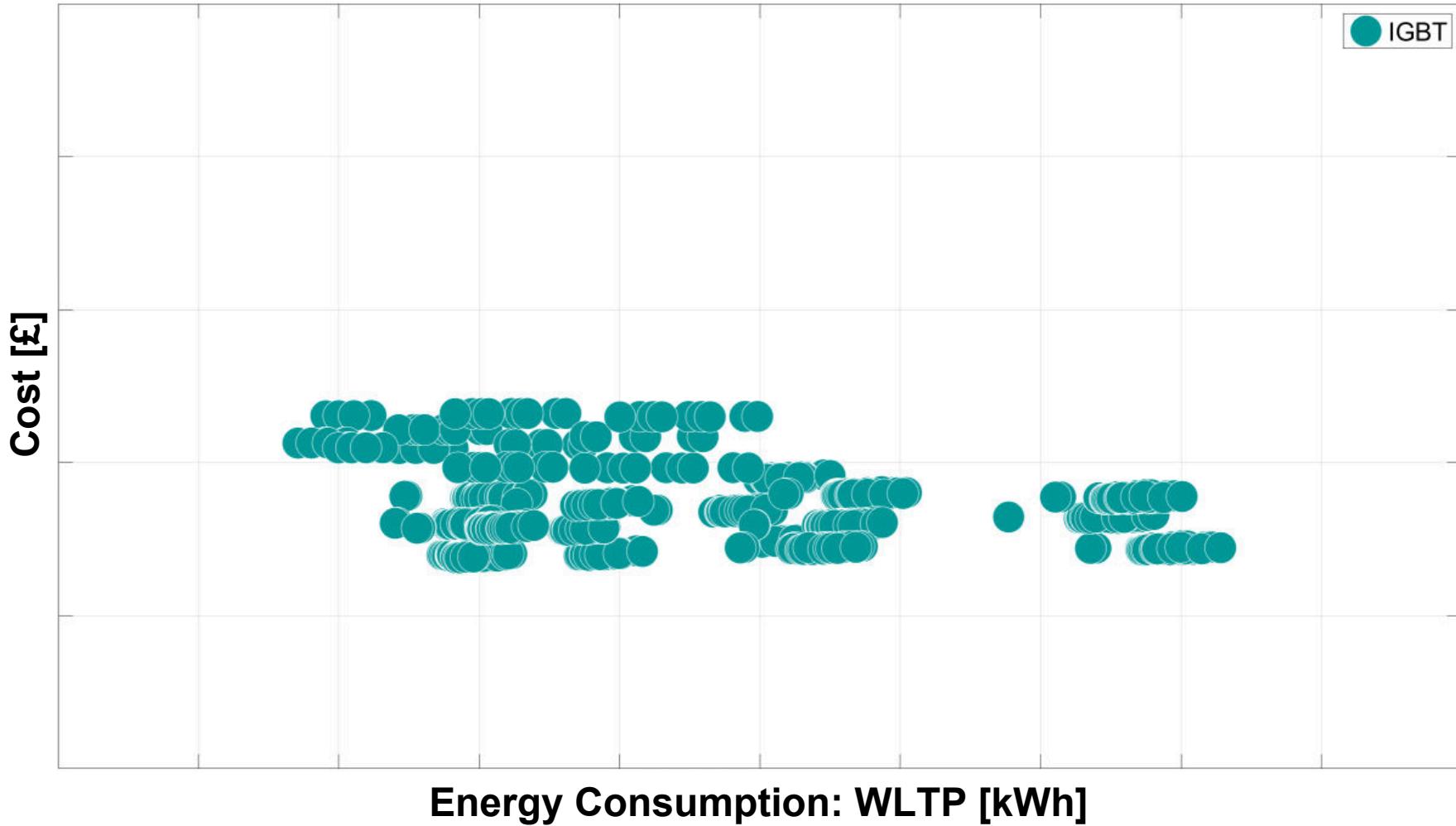


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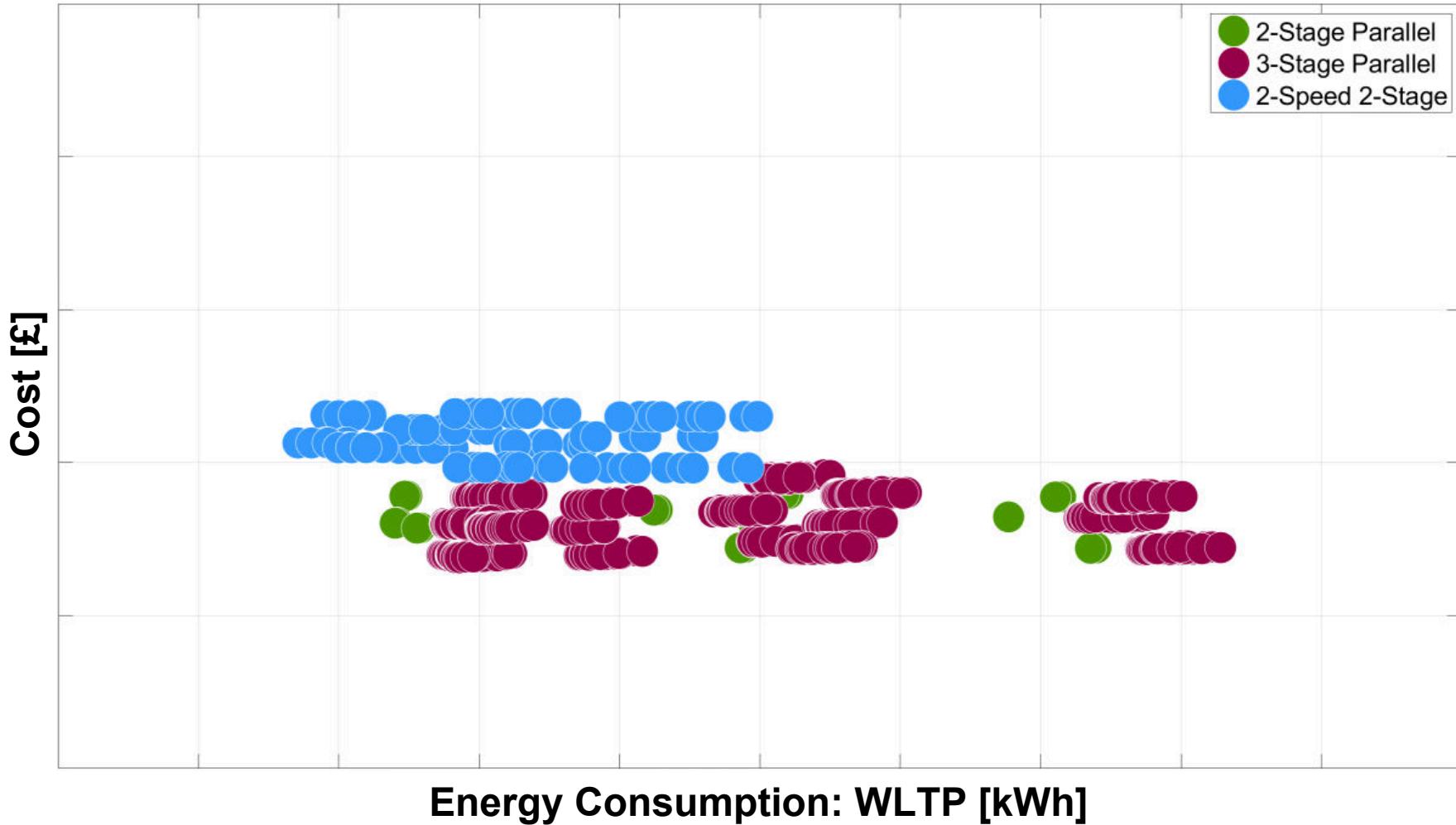


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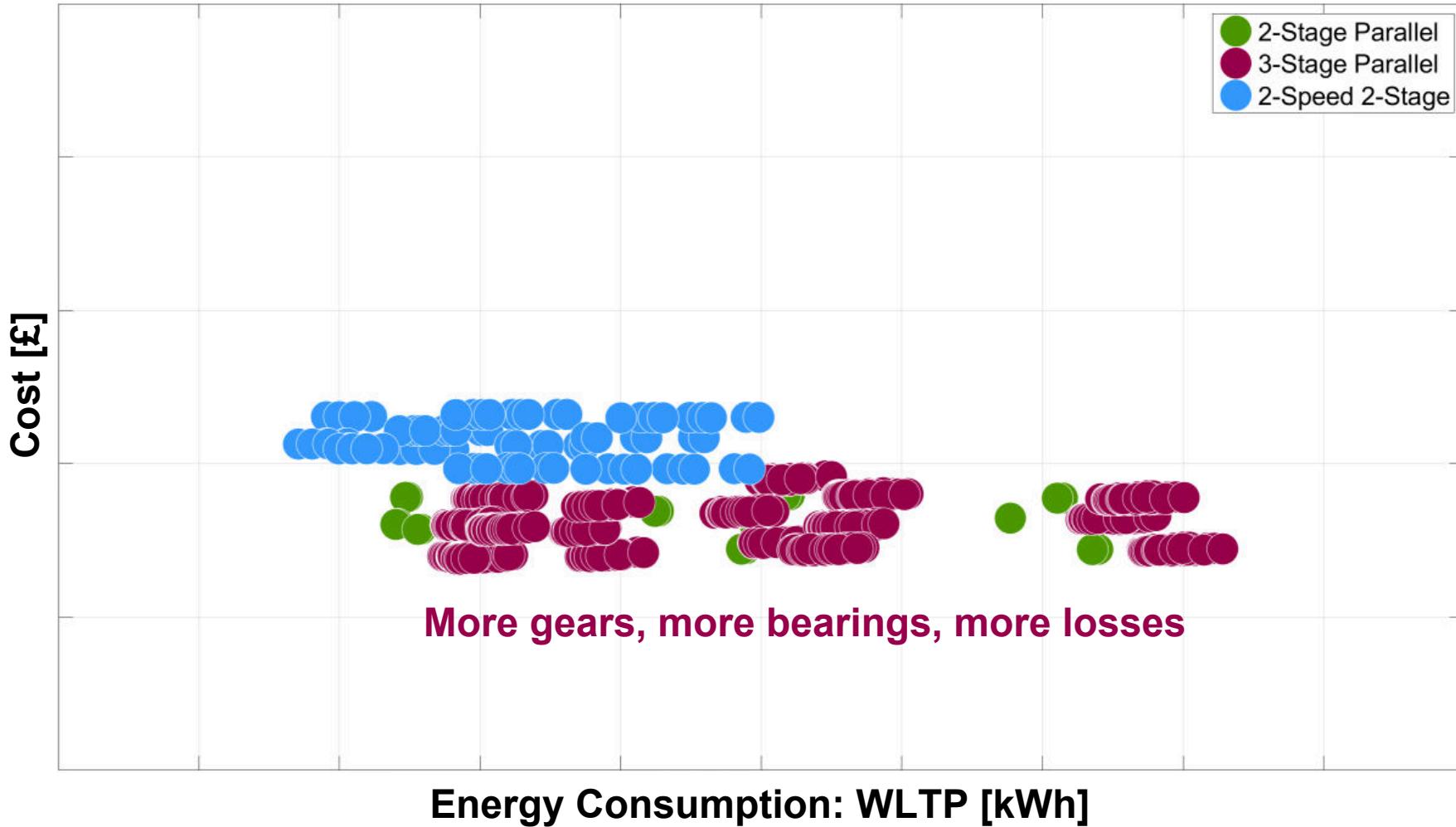


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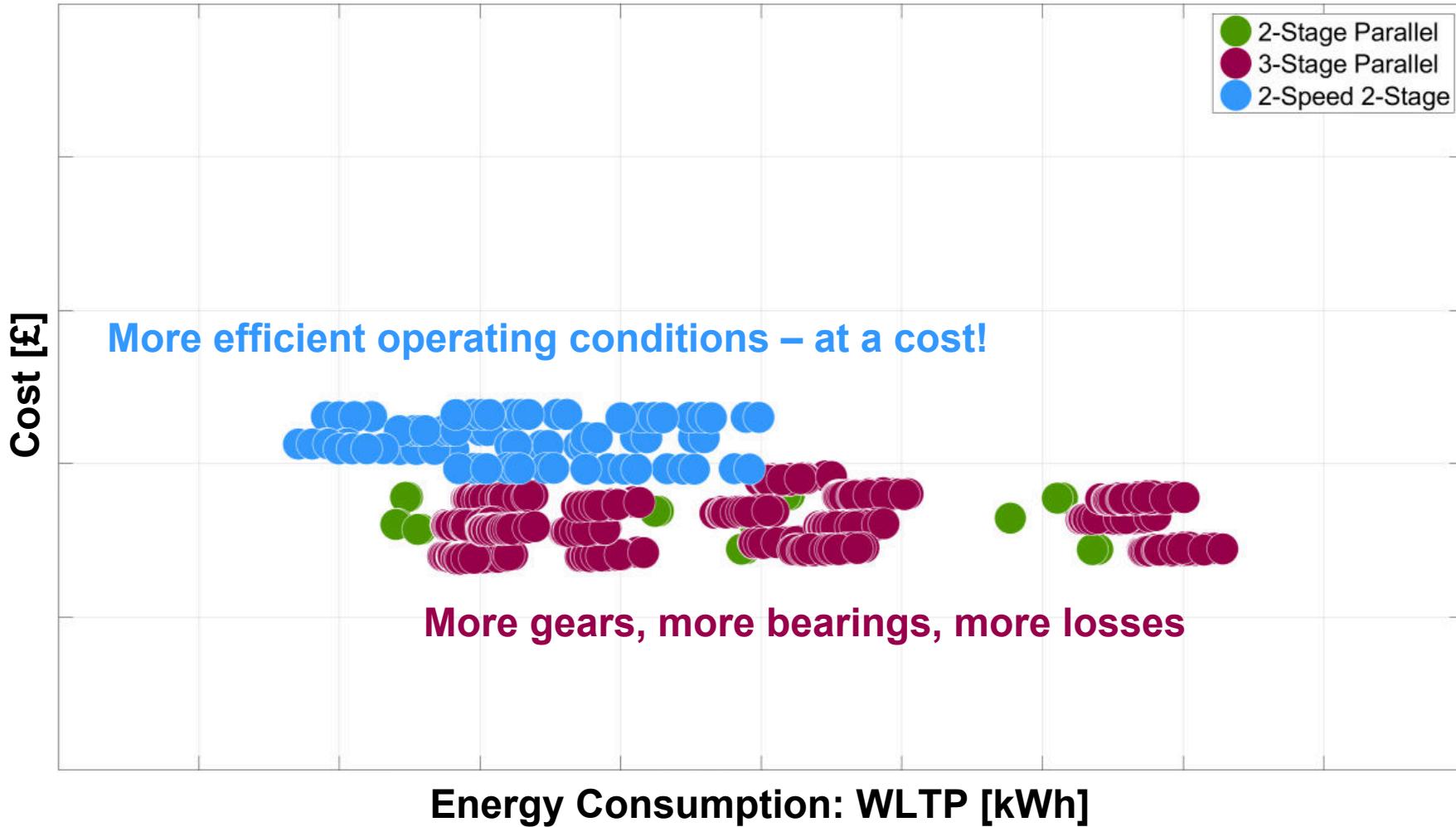


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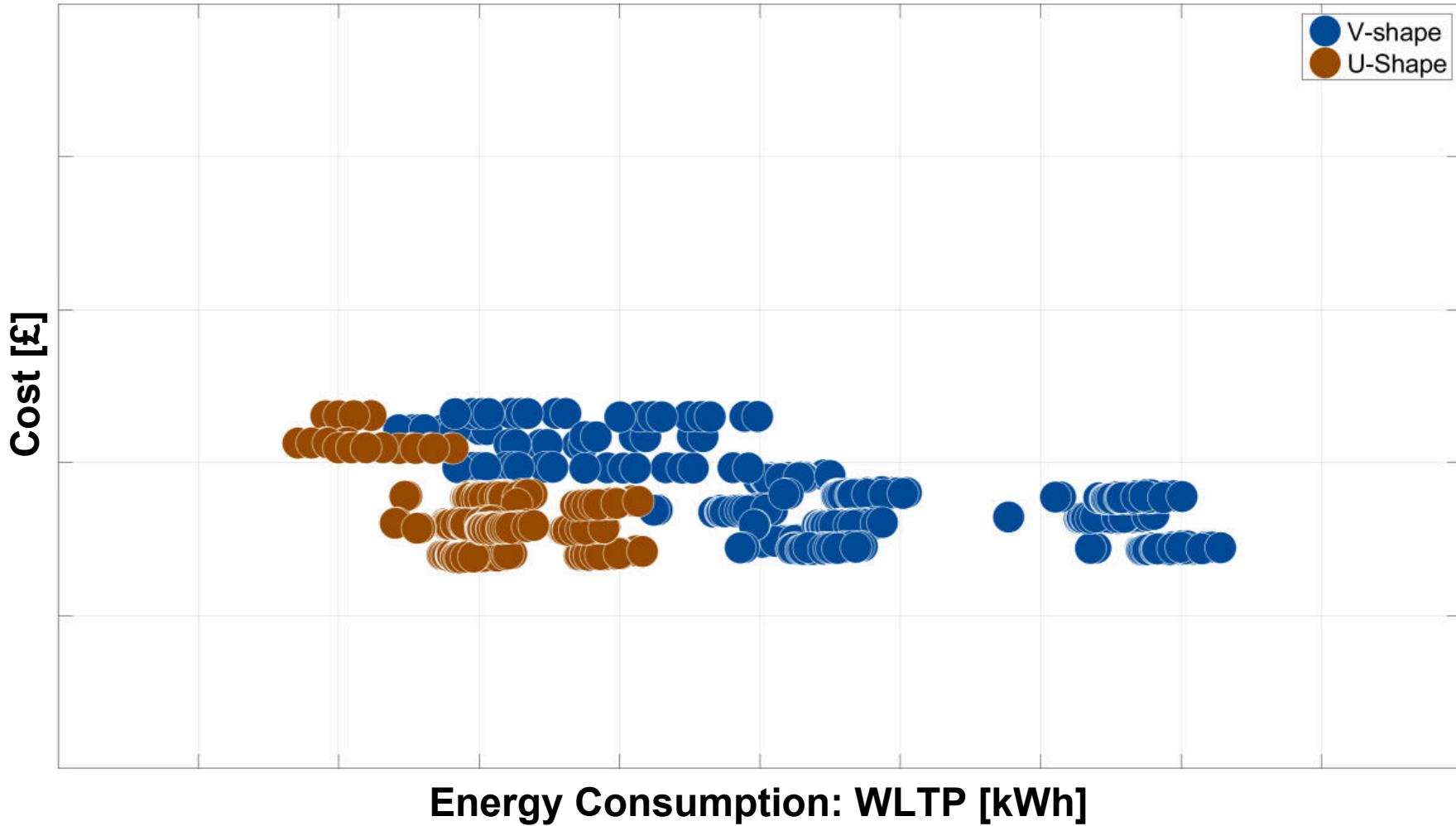


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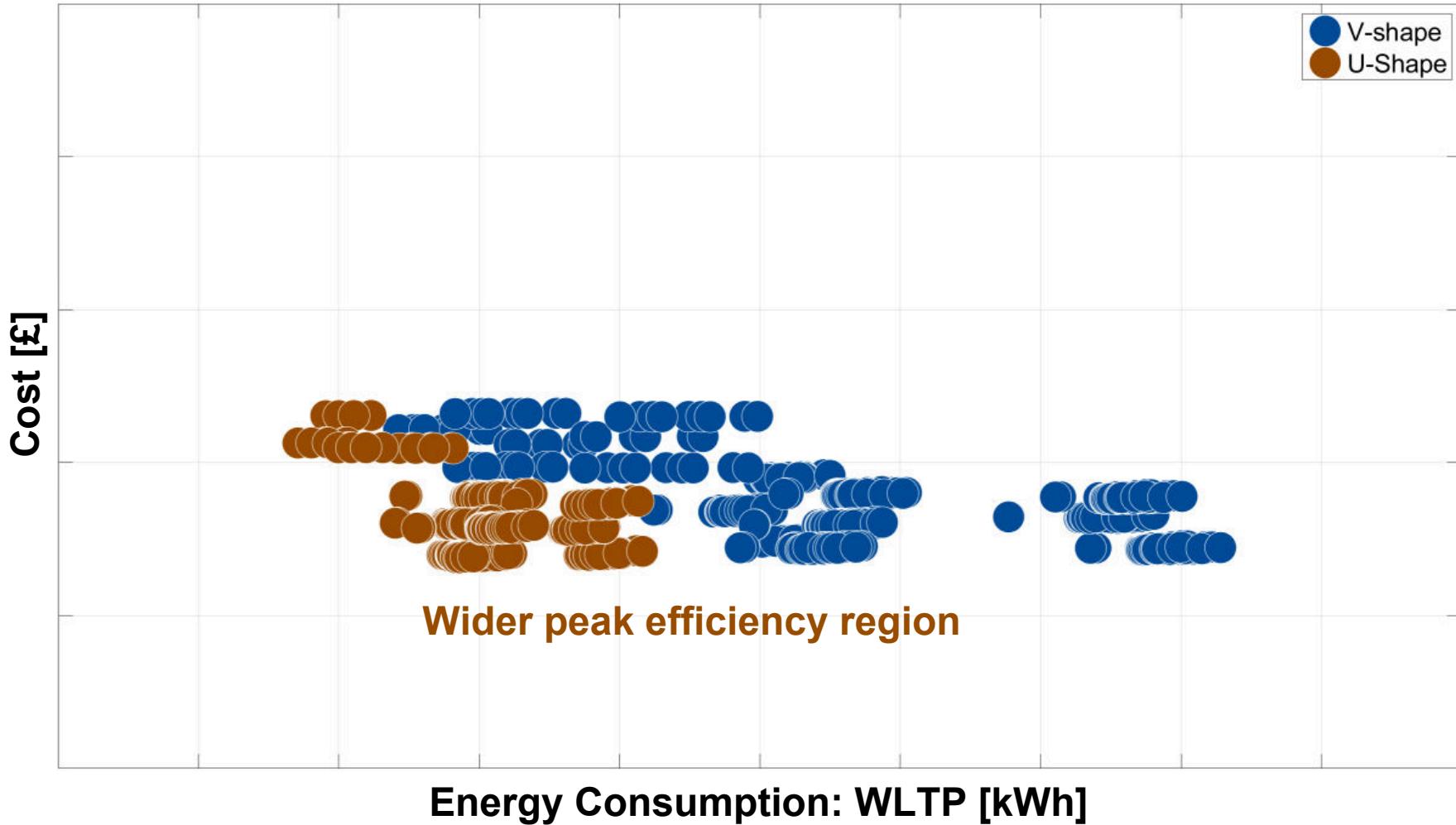


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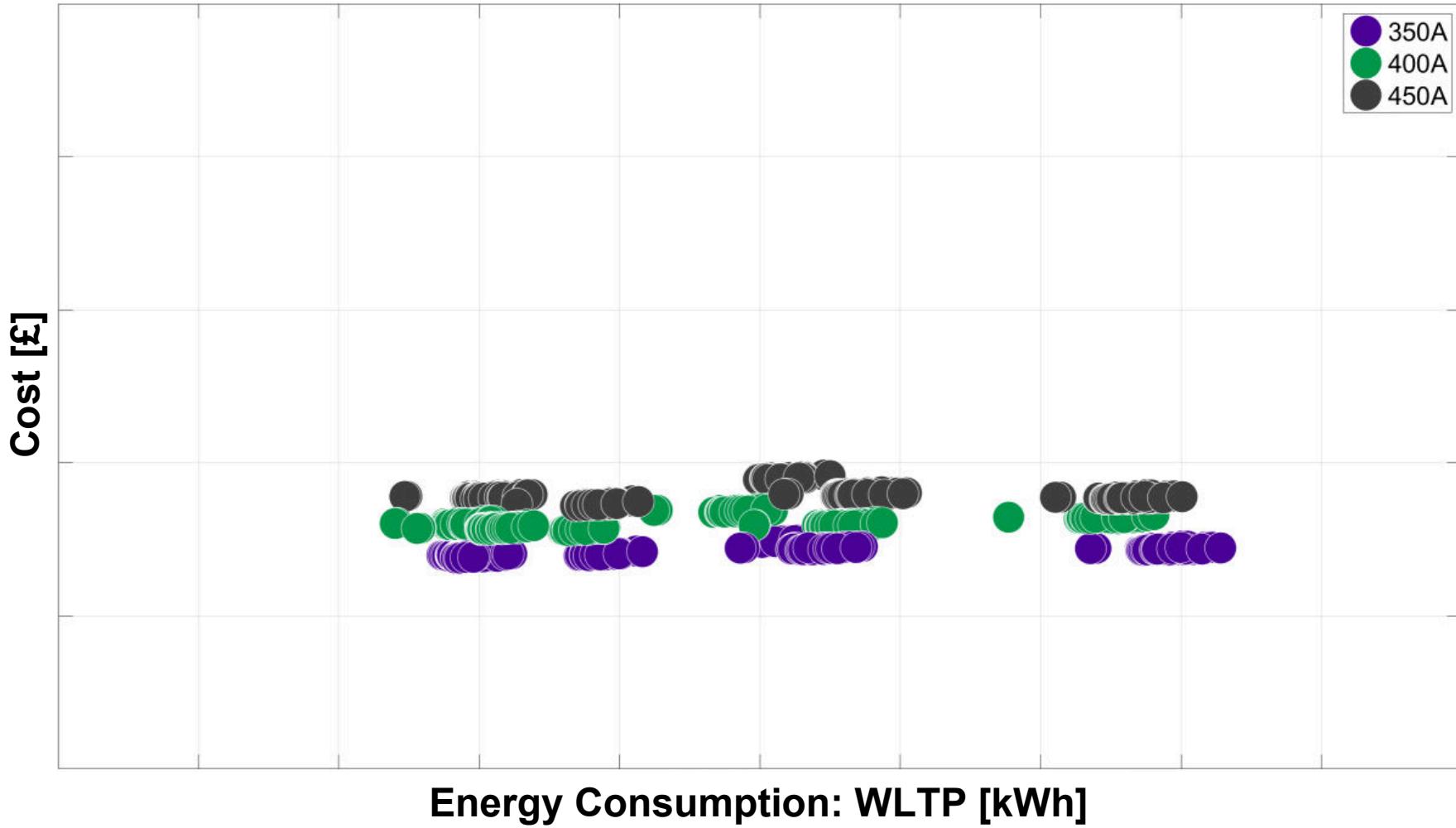


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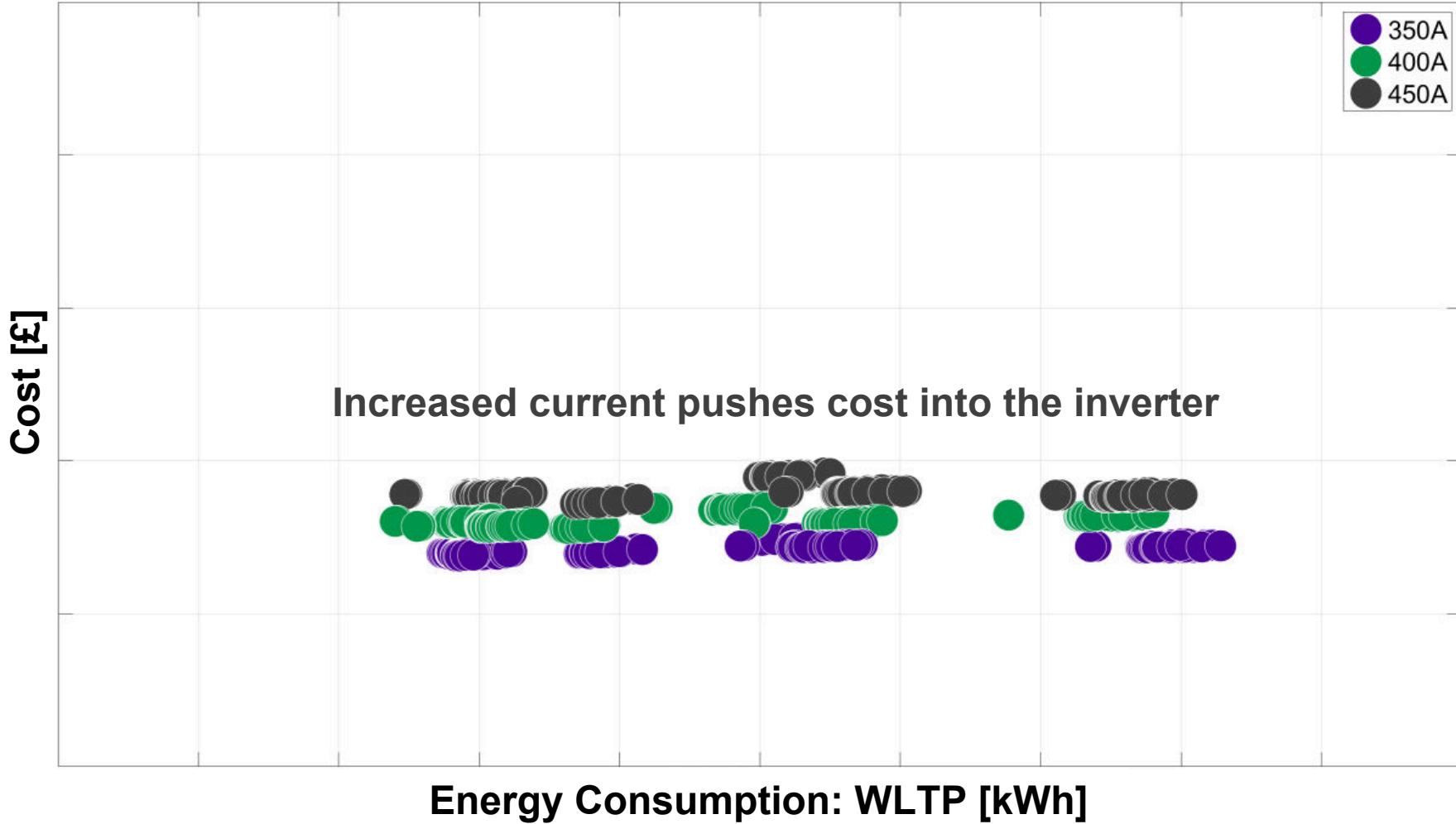


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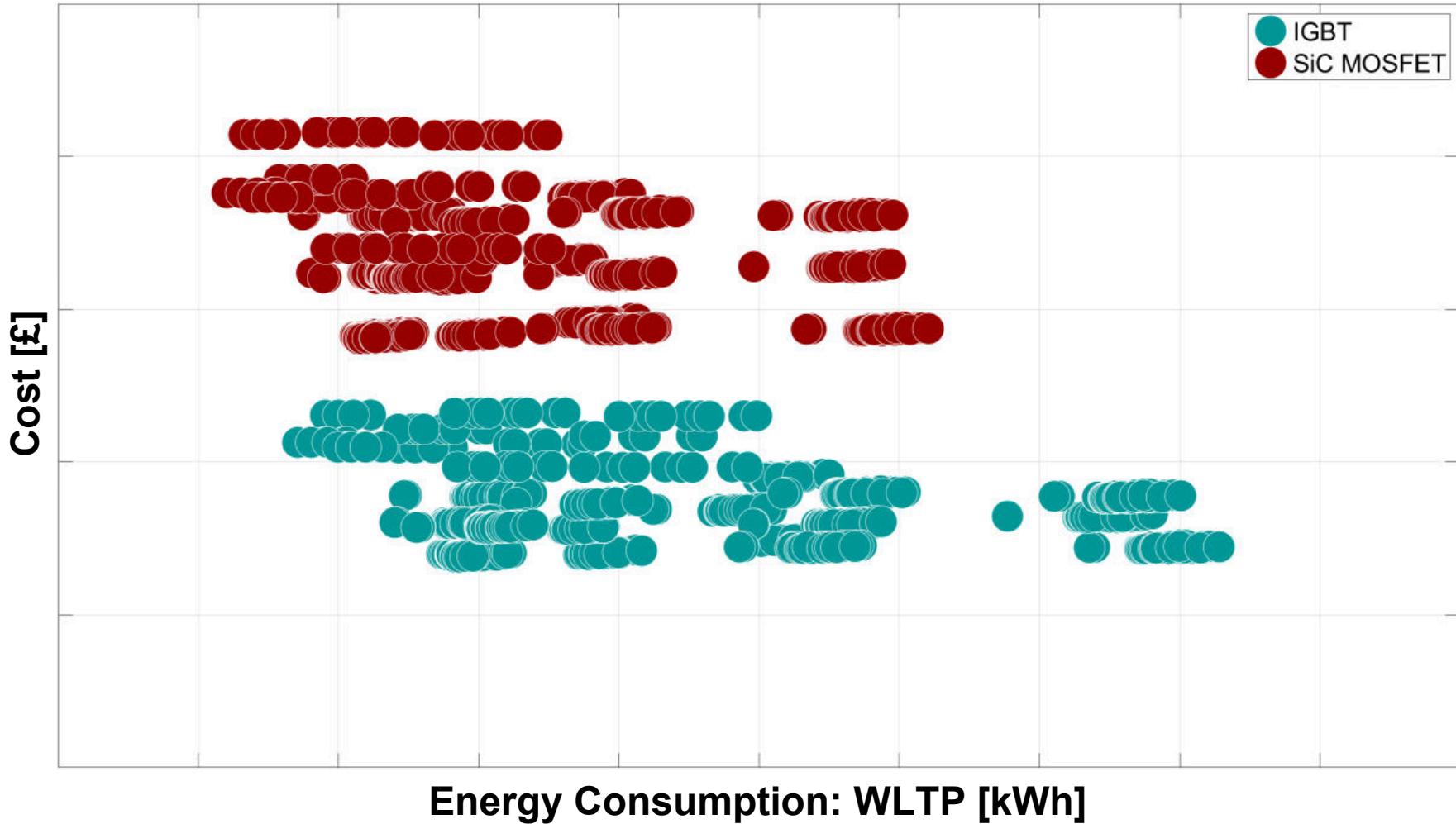


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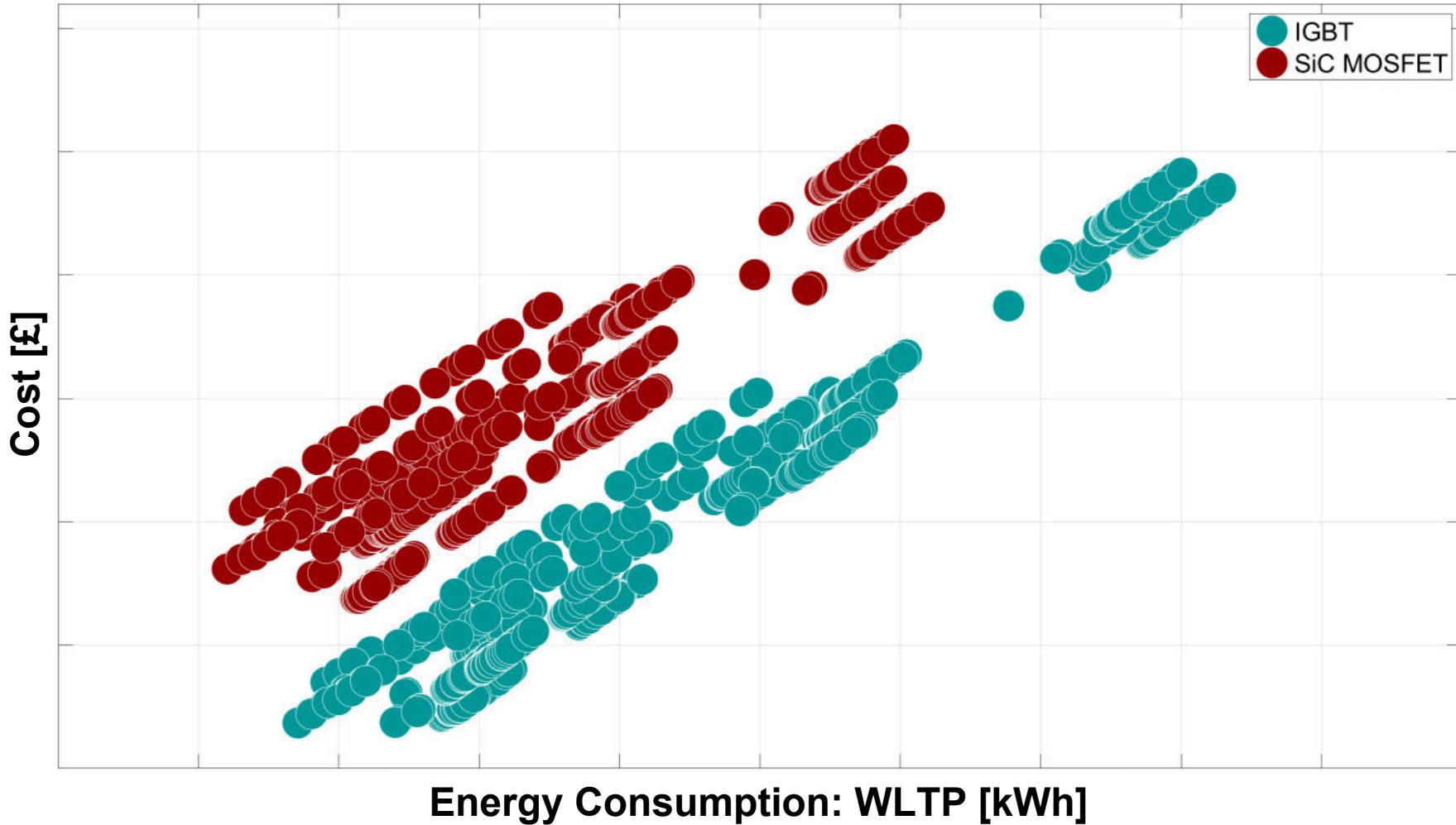


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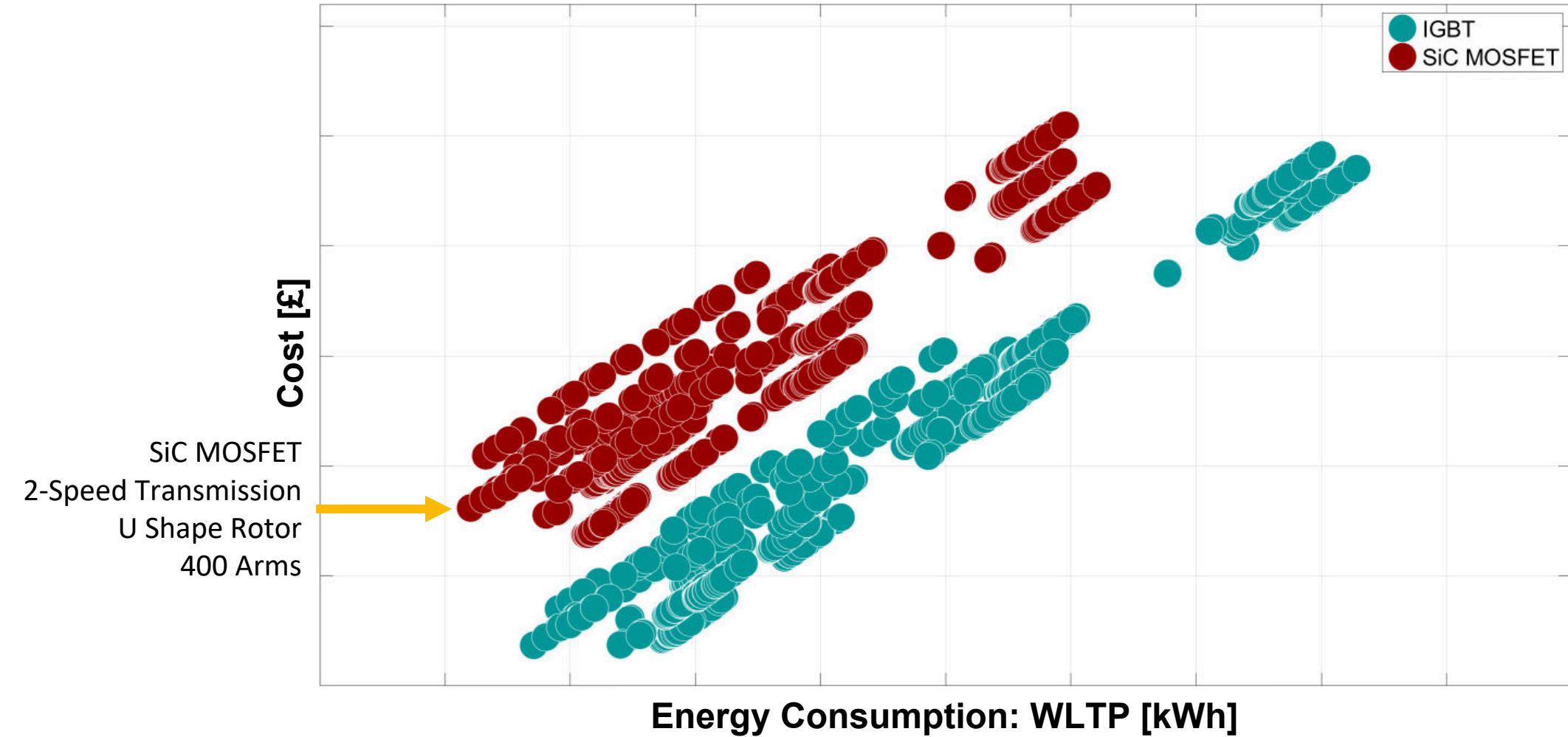


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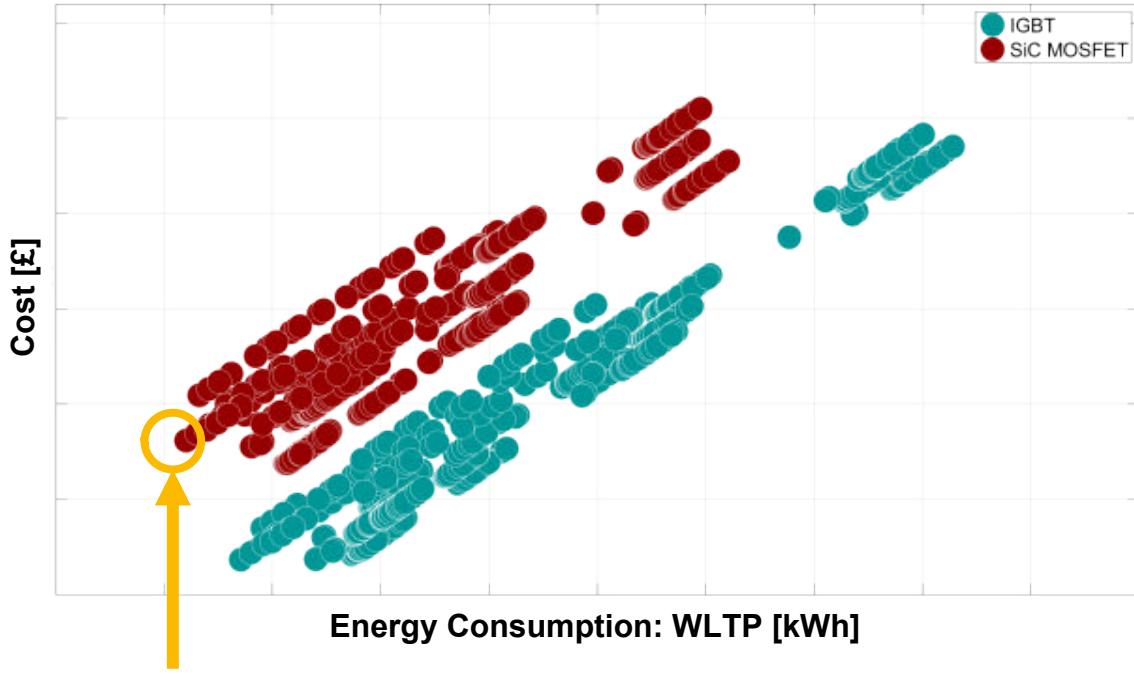


SUMMARY

- Rapid data creation and design space mapping
- Evaluation of complex trade-offs
- Weighted cost function to account for different markets and applications



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Exhibitor Booth F13