A NEW PROCESS FOR THE PRAGMATIC CHOICE OF WIND MODELS IN COMPLEX TERRAIN – QUANTIFICATION OF “SKILL SCORE” AND “COST”

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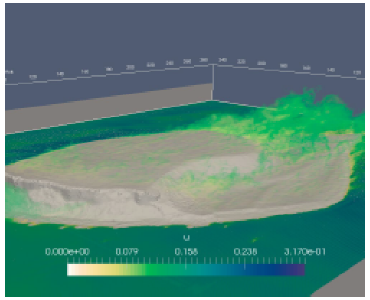
Diverse projects in the new wind energy research programme at HSR

1. DIGITALISATION

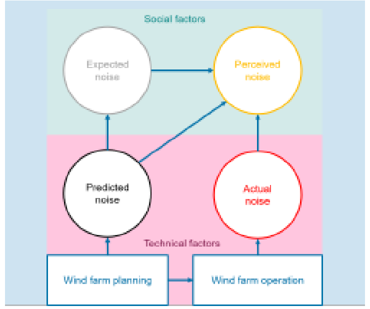


Computational Fluid Dynamics: high-fidelity Large Eddy Simulations and application of the Lattice Boltzmann Method to wind flow in complex terrain (BFE, WindForS).

Internet of Things: design of wireless, smart pressure and acoustic measurement systems for wind turbine blades.

Machine Learning: power curve predictions and SCADA data analysis.

2. HUMAN FACTORS

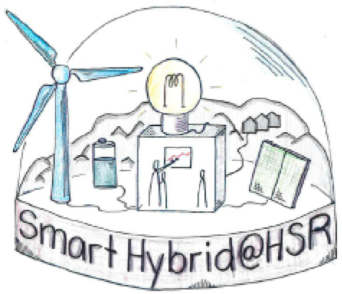


Acceptance: understanding the technical and behavioural factors related to wind turbine noise perception and reality (together with the University of St. Gallen).

Skills: supporting young professionals in leadership skills development (in collaboration with mindspire).

Teaching: developing and applying e-learning methods for wind energy education.

3. SYSTEM INTEGRATION



Microgrids: investigating the possibility of integrating wind energy, photovoltaics and storage systems into closed microgrid systems for improving grid stability.

Innovation: novel energy supply solutions such as kite wind power and building-integrated systems.

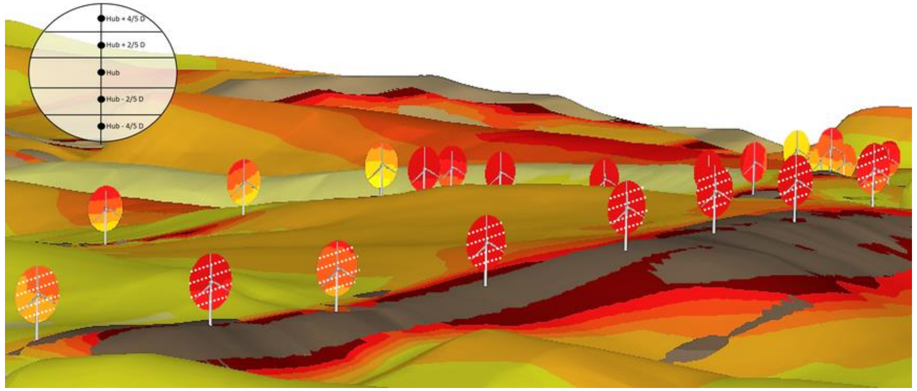
Recycling: designing and testing new bio-materials for wind turbine blades.

Contents

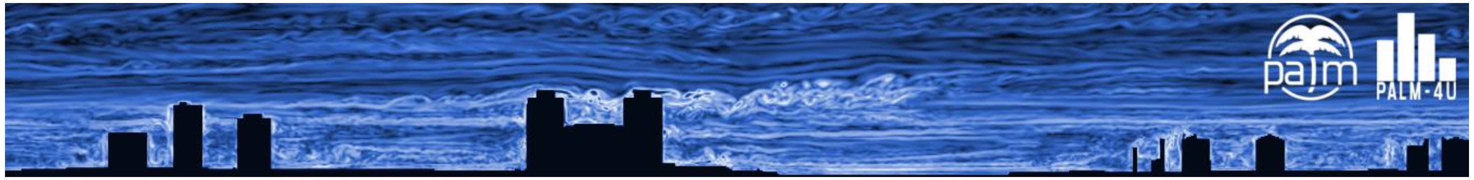
- **The problem.**
- **The solution → project description.**
- **How to quantify "skill" and "costs"?**
- **Pre-study – Bolund Hill.**
- **Conclusions.**

The problem: which tool is best for my application?

- **Accuracy of wind resource estimation → large effect on expected rate of return.**
- **Complex weather and wind flow → wind modelling is very challenging.**
- **Wide range of simulation tools with varying accuracies and costs → which is best???**
  - Wrong choice → resources wasted or the rate of return is inaccurate → investors lose money.
  - No guidelines or tools → gut feeling!

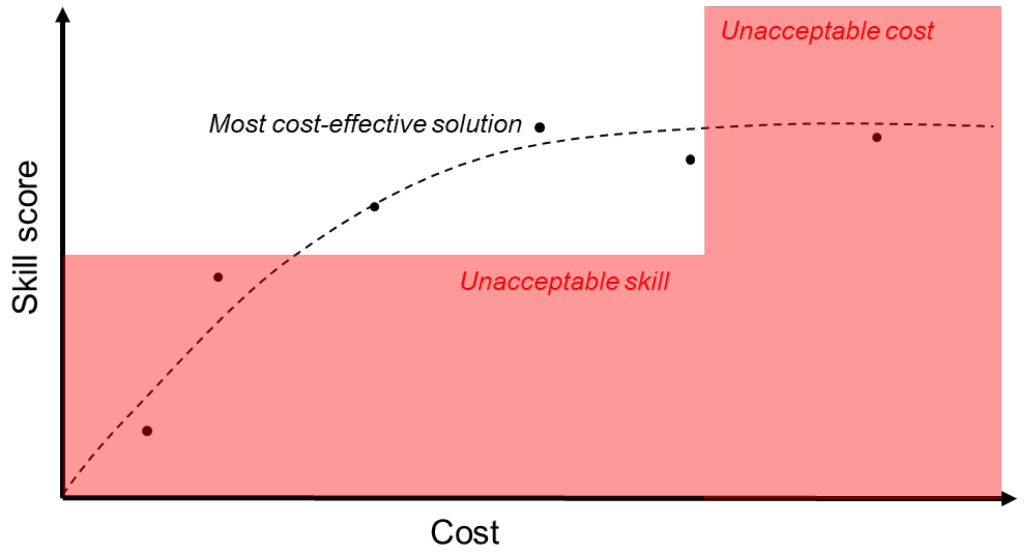






The solution: new decision process

- **Goal =** development of a **new industry-relevant decision process** for selecting the wind model that gives the best results with the least computational effort and costs for any given wind energy project, with a focus on **complex terrain**.

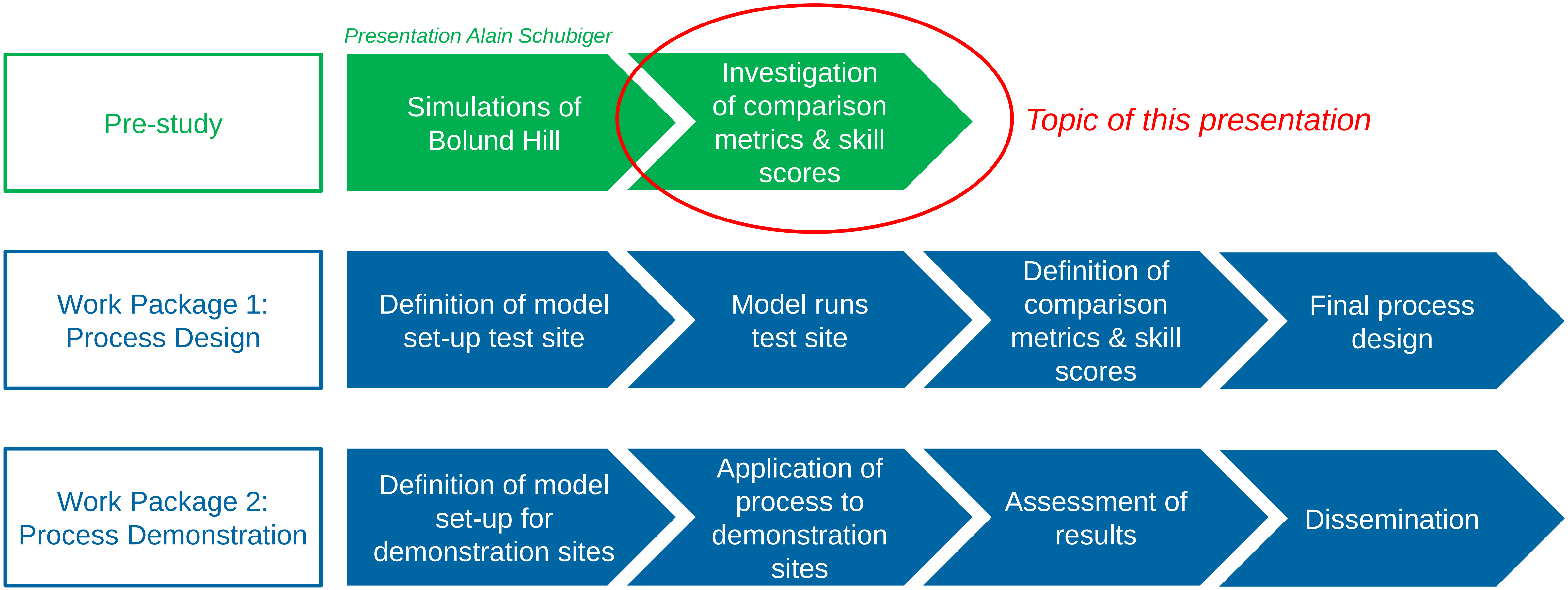


- **Benefits:** quicker and more reliable choice of wind resource assessment tool, optimal usage of resources and optimal accuracy of results.

Project description – wide variety of models chosen

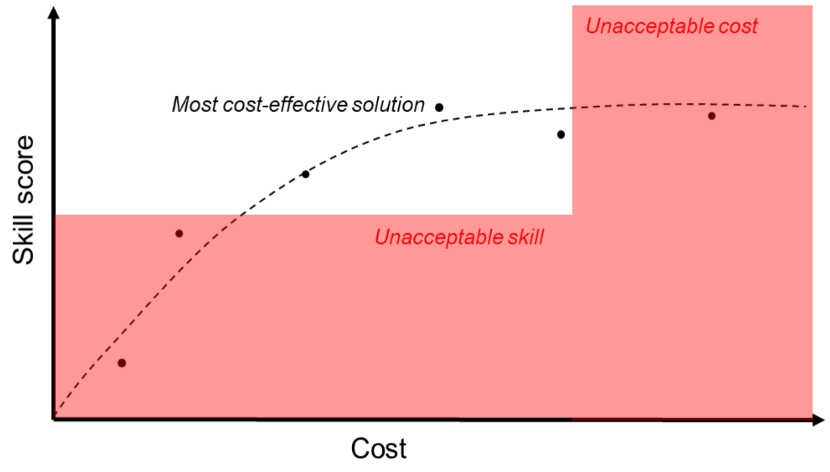
Model	HSR	Meteotest	HSE
WAsP		X	
WindSim		X	
PALM (LES)		X	
Fluent (RANS)	X		
Fluent (LES)	X		
Palabos (LBM)	X		
OpenFOAM (RANS)			X
OpenFOAM (DES)			X

Project description – work packages and tasks



How to quantify "skill" and "costs"??

- **Some parameters can be estimated before doing the simulations.**
- **But…..some can only be calculated afterwards!**
- **The goal is to produce this type of diagram beforehand so that the best tool can be chosen for a given project.**



- **Planned process:**
  1. Make estimates beforehand using scale of 0-100% (with weighting 0-100%).
  2. For one test case, do simulations for all tools and quantify the actual costs and skill.
  3. Repeat for varying input conditions.
  4. Compare estimated to actual costs and skill → develop scaling factors to choose tool **beforehand**.
- **Initial study for Bolund Hill in this work.**

Relevant parameters – skill beforehand

	Skill score (estimated)		
	Model	**Input data**	
Underlying equations and turbulence model	Aerodynamic assumptions	Terrain complexity	*e.g. RIX value*
Underlying equations and thermodynamic model	Thermodynamic assumptions	Surface roughness complexity	*e.g. Number of surface roughness interfaces*
Orthogonal quality, skewness, aspect ratio	Grid quality	Atmospheric stability	*Turbulence intensity, shear factor and Richardson number*
Number of cells, value of y+ if relevant	Grid resolution	Quality of comparison data	*Number of met masts and sensors, calibration and quality of sensors, length of measurement campaign*
Ability of 3D grid to adapt to terrain	Terrain approximation	Quality of terrain data	*Number of met masts and sensors, calibration and quality of sensors, length of measurement campaign*
		Quality of surface data	*Resolution, source quality*
		Quality of atmospheric data	*Source quality and length*

Relevant parameters – costs beforehand

Costs (estimated)	
Investment	**Time**
Software costs	Time to learn model and training costs
	Changes to standard processes
	Expected simulation set-up effort
	Expected simulation run-time
	Expected post-processing effort

e.g. Available file formats, GUIs, programming required (Expected simulation set-up effort)

Relevant parameters – skill afterwards

Skill score (actual)			
Wind speed	Wind direction	Shear factor	Turbulence intensity
Absolute difference			
Relative difference			
Correlation coefficient			

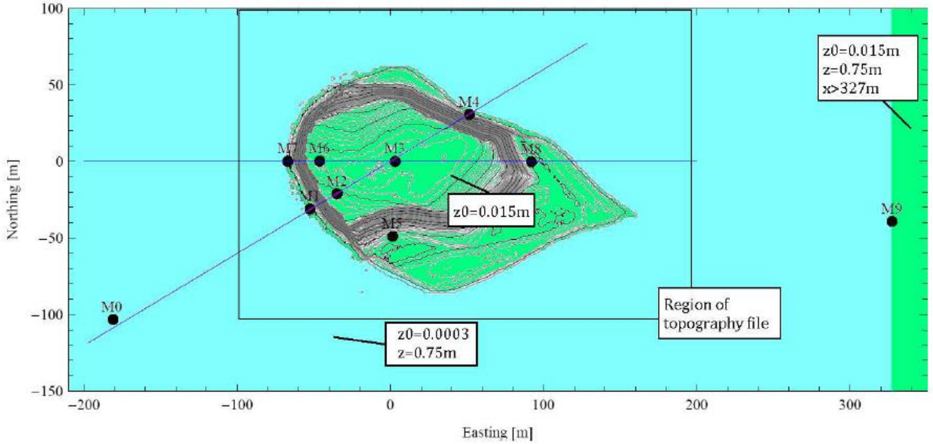
Relevant parameters – costs afterwards

Costs (actual)

Investment	Time
Software costs	Time to learn model and training costs
	Changes to standard processes
	Actual simulation set-up effort
	Actual simulation run-time
	Actual post-processing effort

Pre-study – Bolund Hill

- **Bolund Hill case:**



- **Results available:**
  - Palabos LBM/LES (Alain Schubiger).
  - Fluent LES (Alain Schubiger).
  - WindNinja-CFD (Natalie Wagenbrenner).
  - WindNinja-COM (Natalie Wagenbrenner).

Parameter quantification – method

- **For each model and for cost and skill both before and after the simulations:**

Definition of weighting for each parameter (%) → Definition of score for each parameter (%) → Calculation of weighted score → Calculation of total score

$$Weighted\ score\ (\%) = \frac{Score\ (\%) \times Weighting\ (\%)}{100}$$

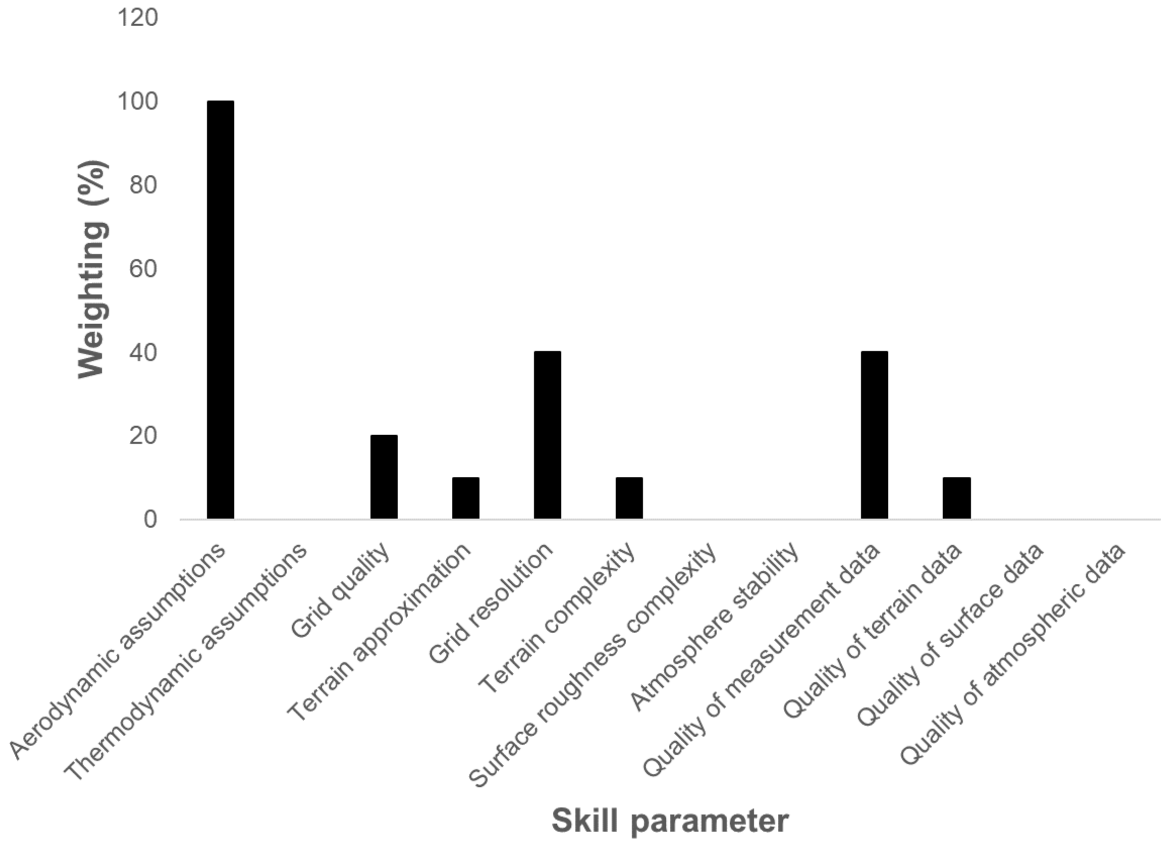
$$Total\ score\ (\%) = 100 \times \frac{\sum Weighted\ scores}{\sum Weighting}$$

Constant factor

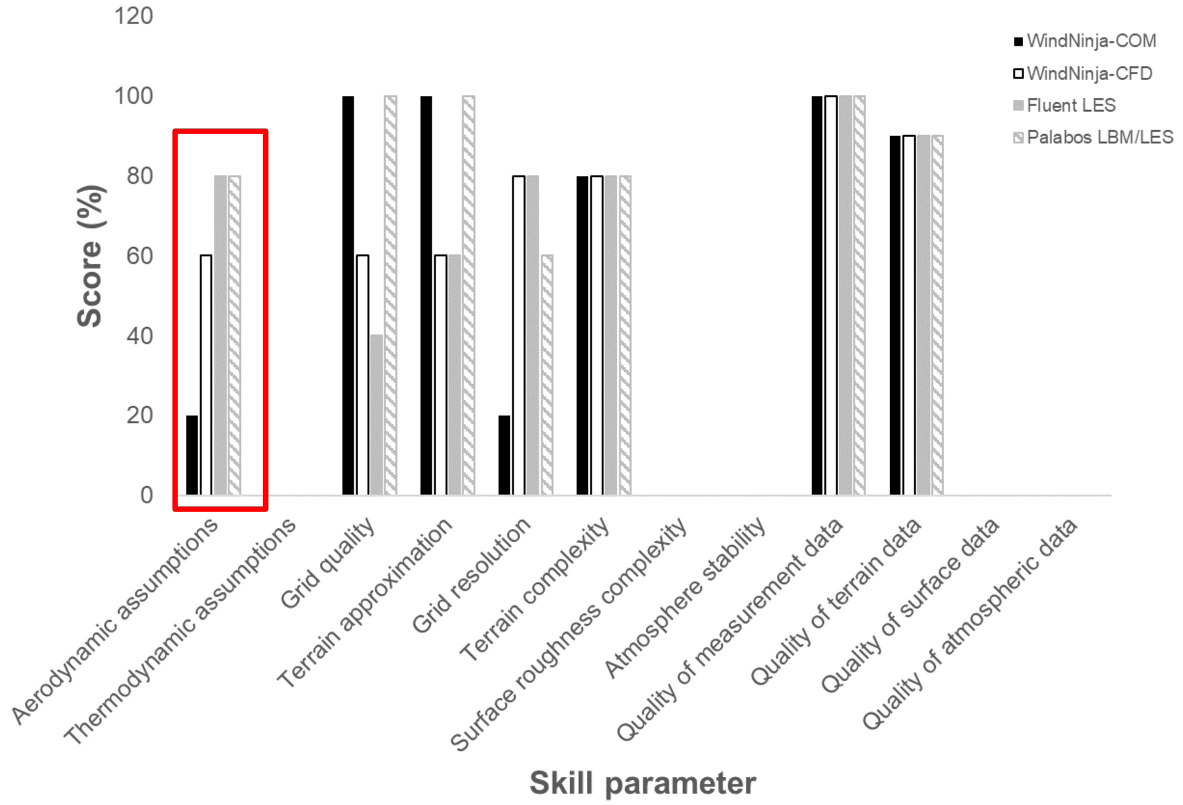
- **For this study, most scores have been approximately estimated → better quantification required!**
  - Exception = skill score afterwards (based on comparison between simulations and measurements).

Parameter quantification – skill beforehand

Chosen weighting:

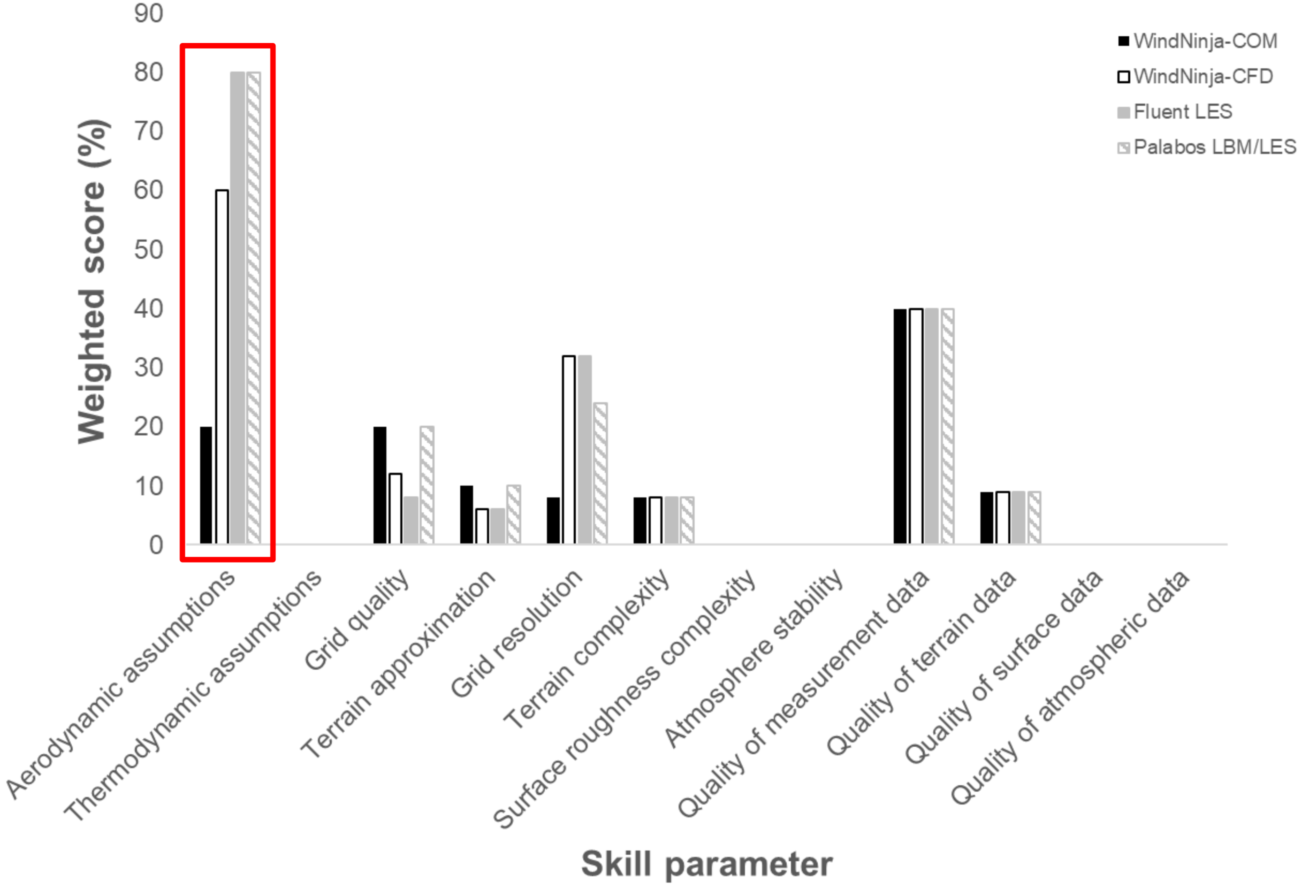


Score:

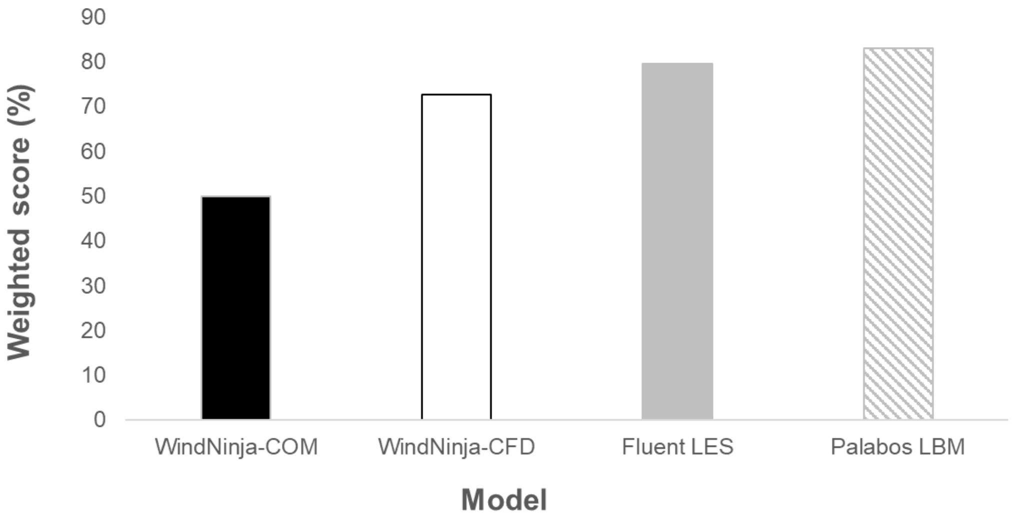


Parameter quantification – skill beforehand

Weighted score:

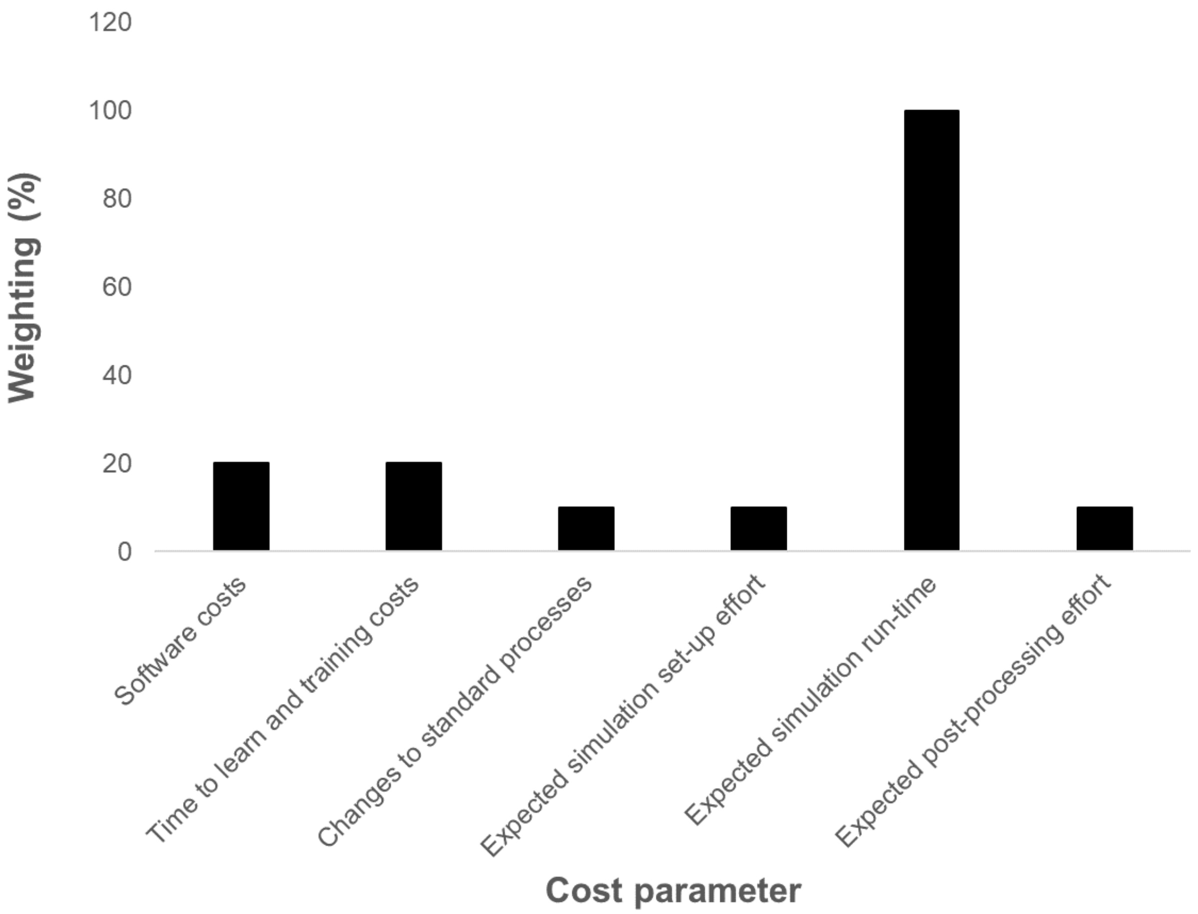


Total scores:

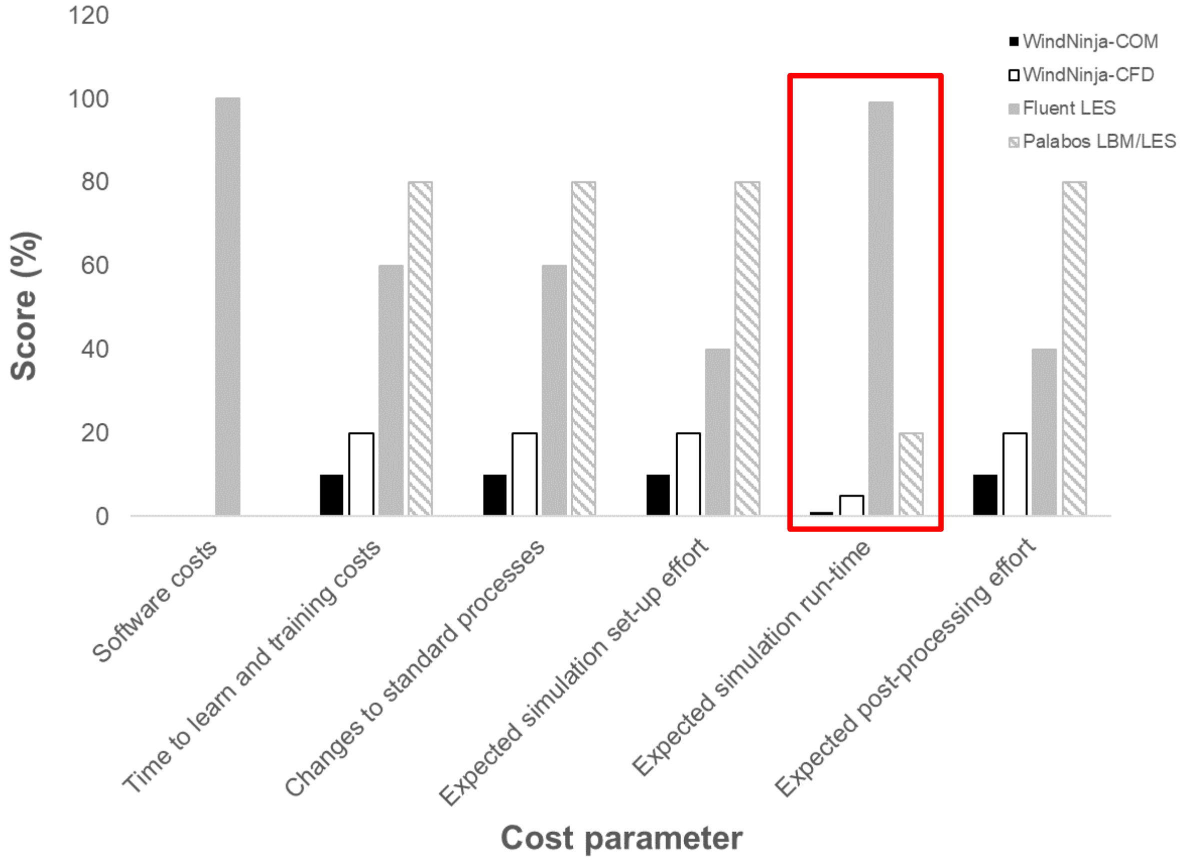


Parameter quantification – cost beforehand

Chosen weighting:



Cost:



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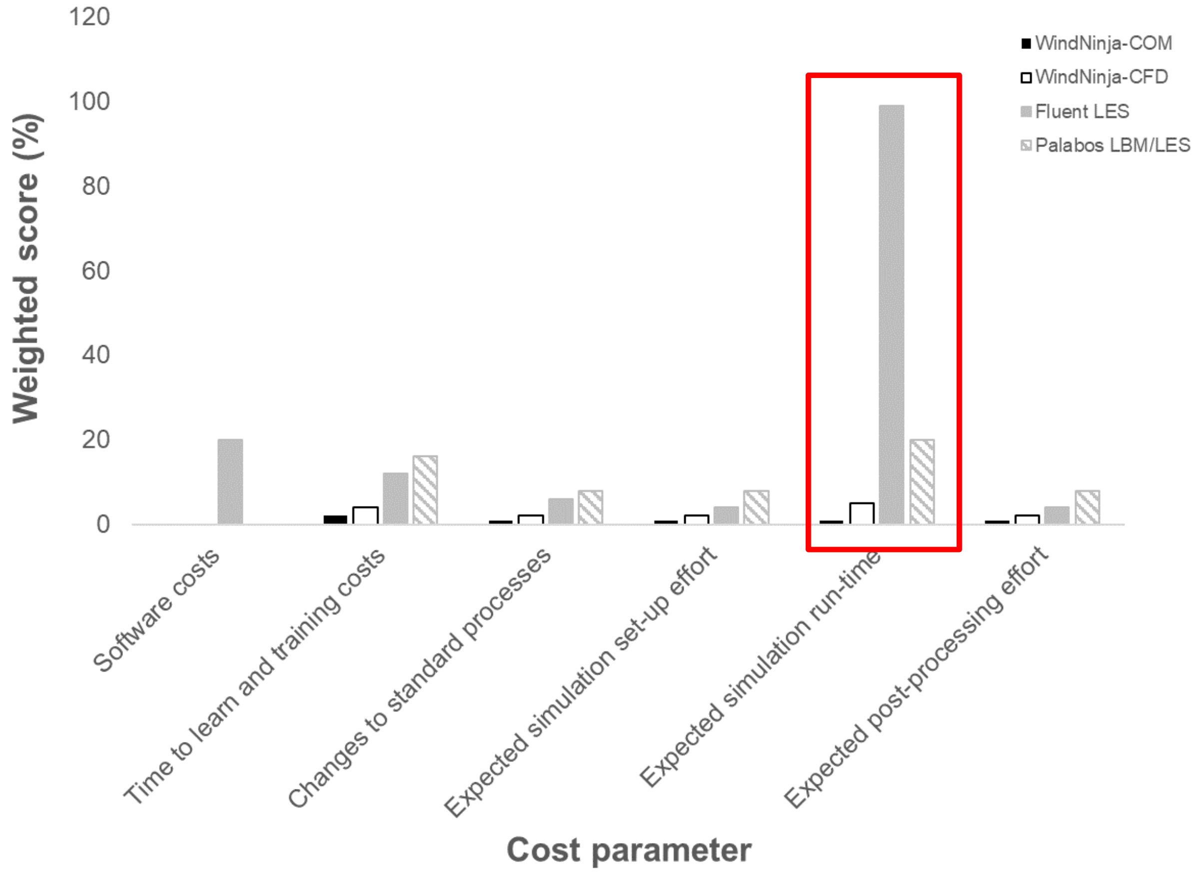
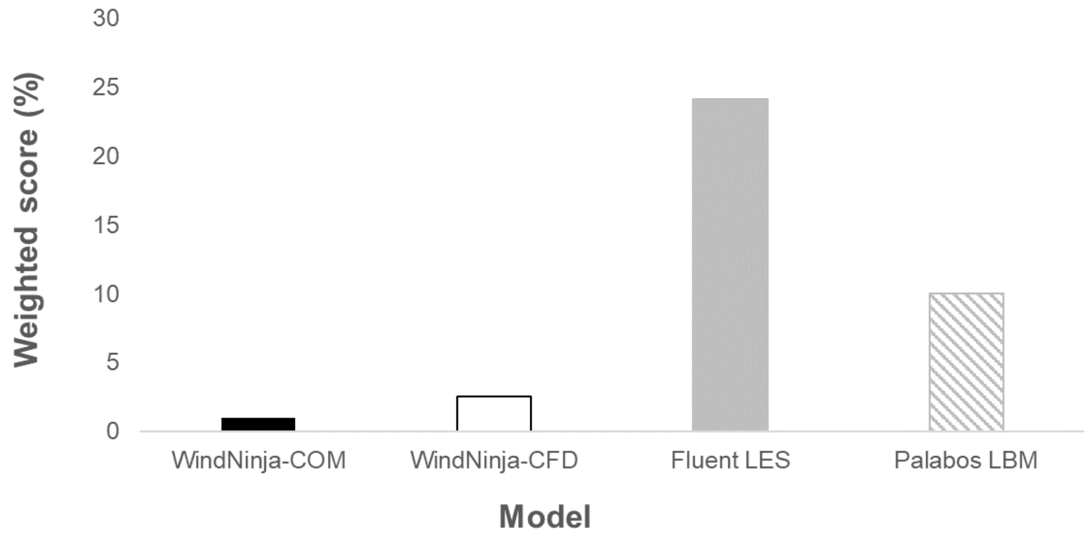
Parameter quantification – cost beforehand

Weighted score:

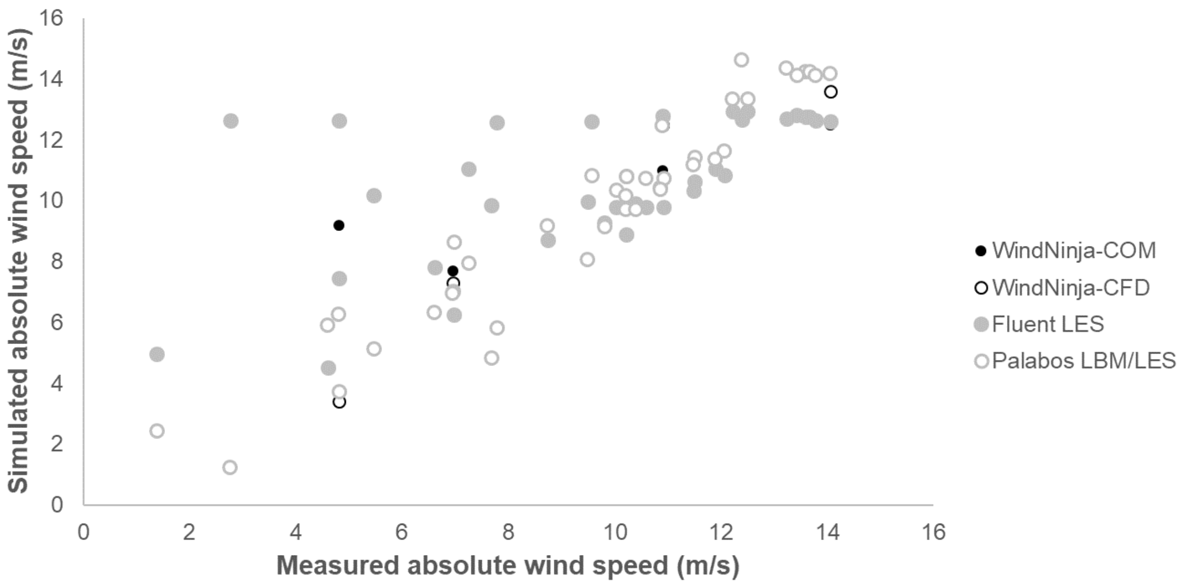


Total scores:

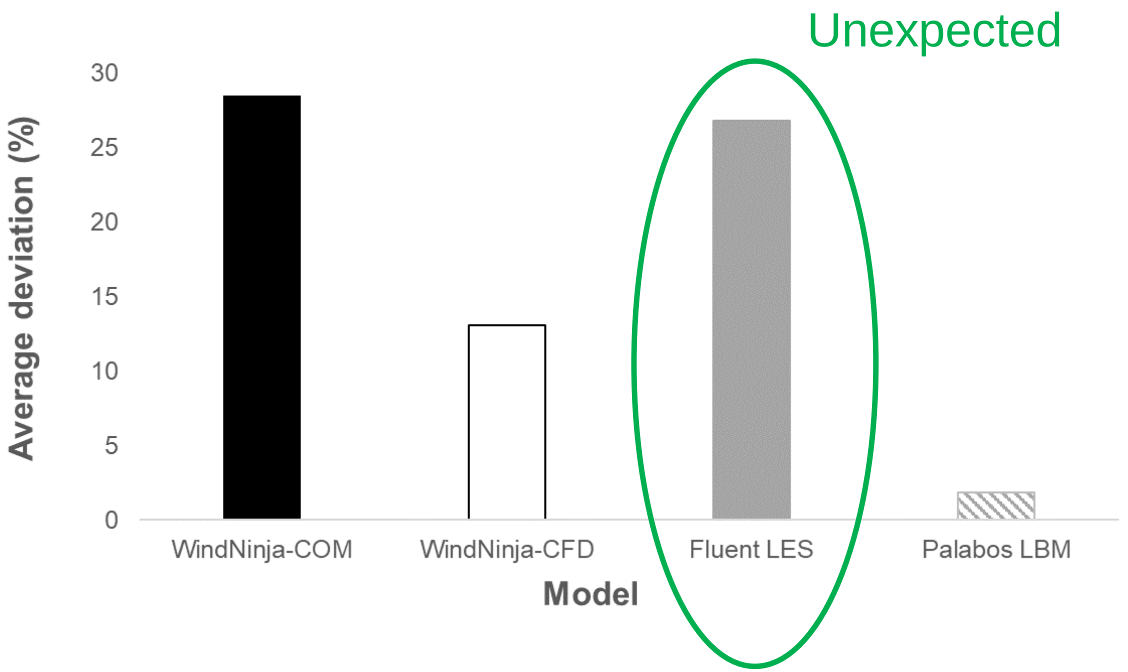


Parameter quantification – skill after

Simulated vs. measured wind speeds:



Average wind speed deviation:



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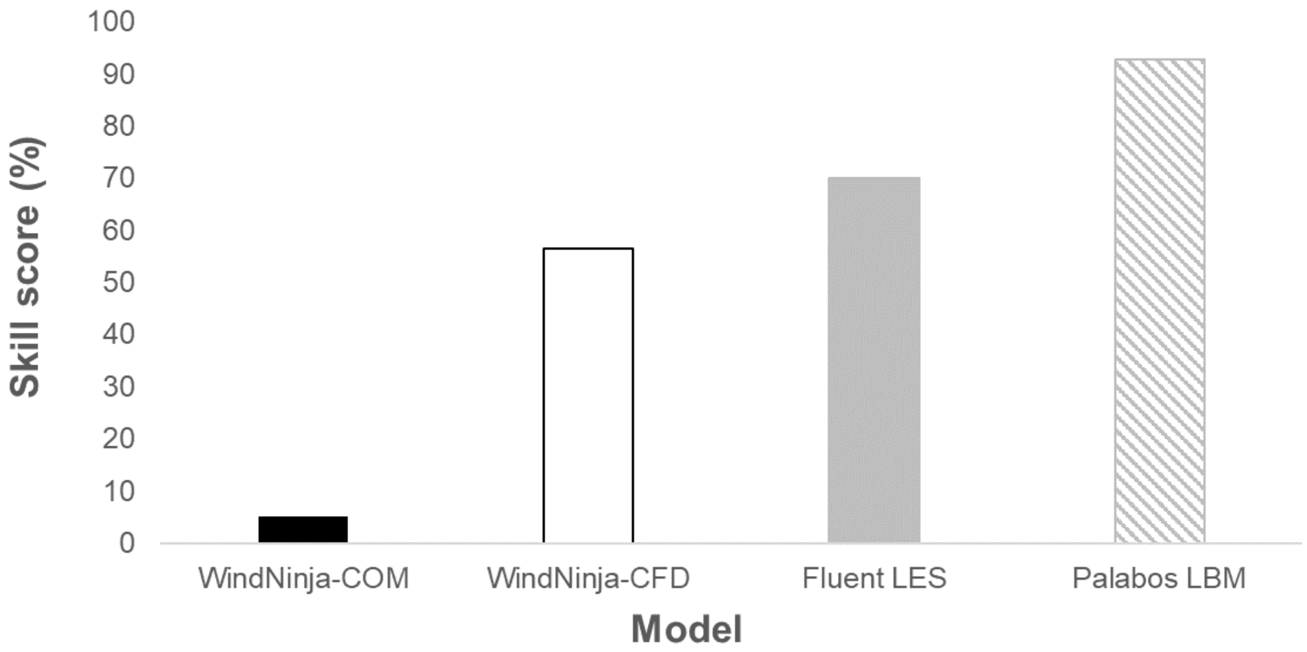
Parameter quantification – skill after

$$Skill\ score = 100 \times \left(1 - \frac{Deviation}{30}\right)$$

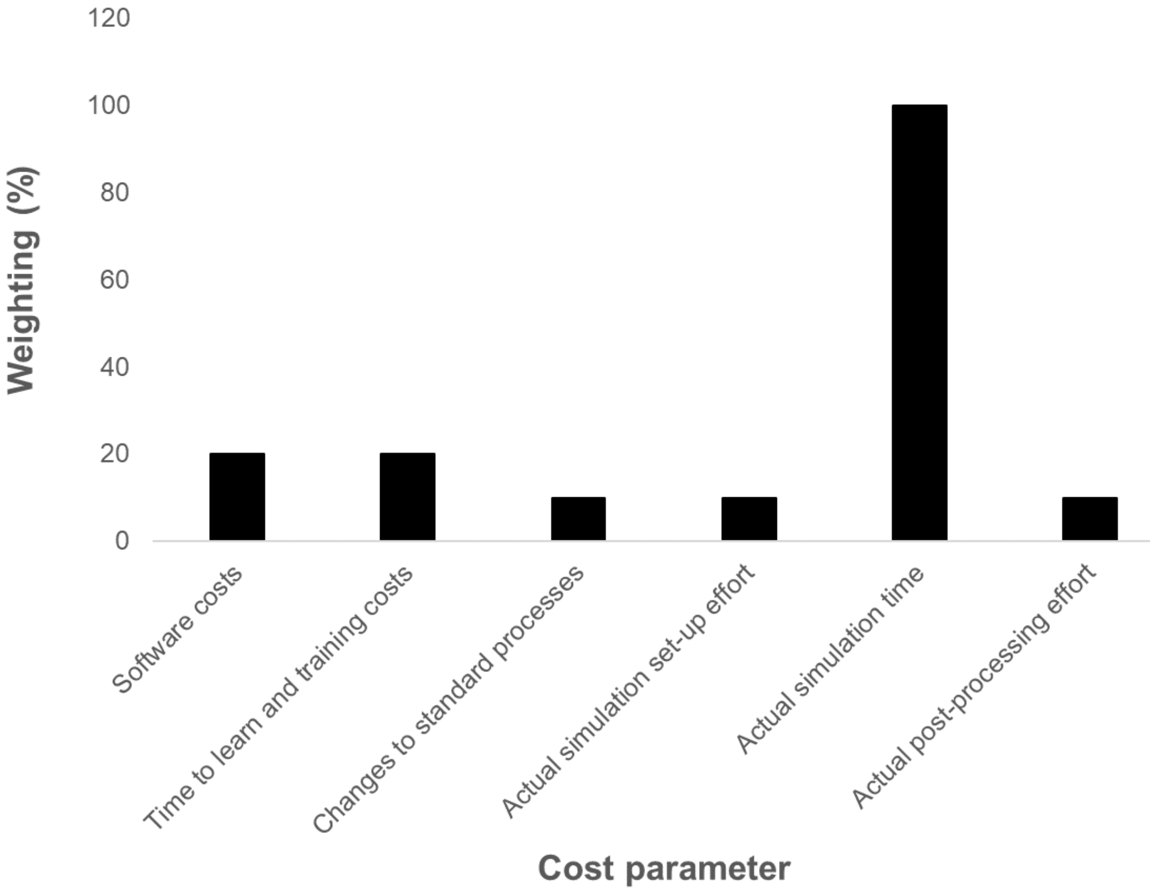
Assumes a linear variation of skill score from 0-100% for deviations between 0 and 30%

Skill score:

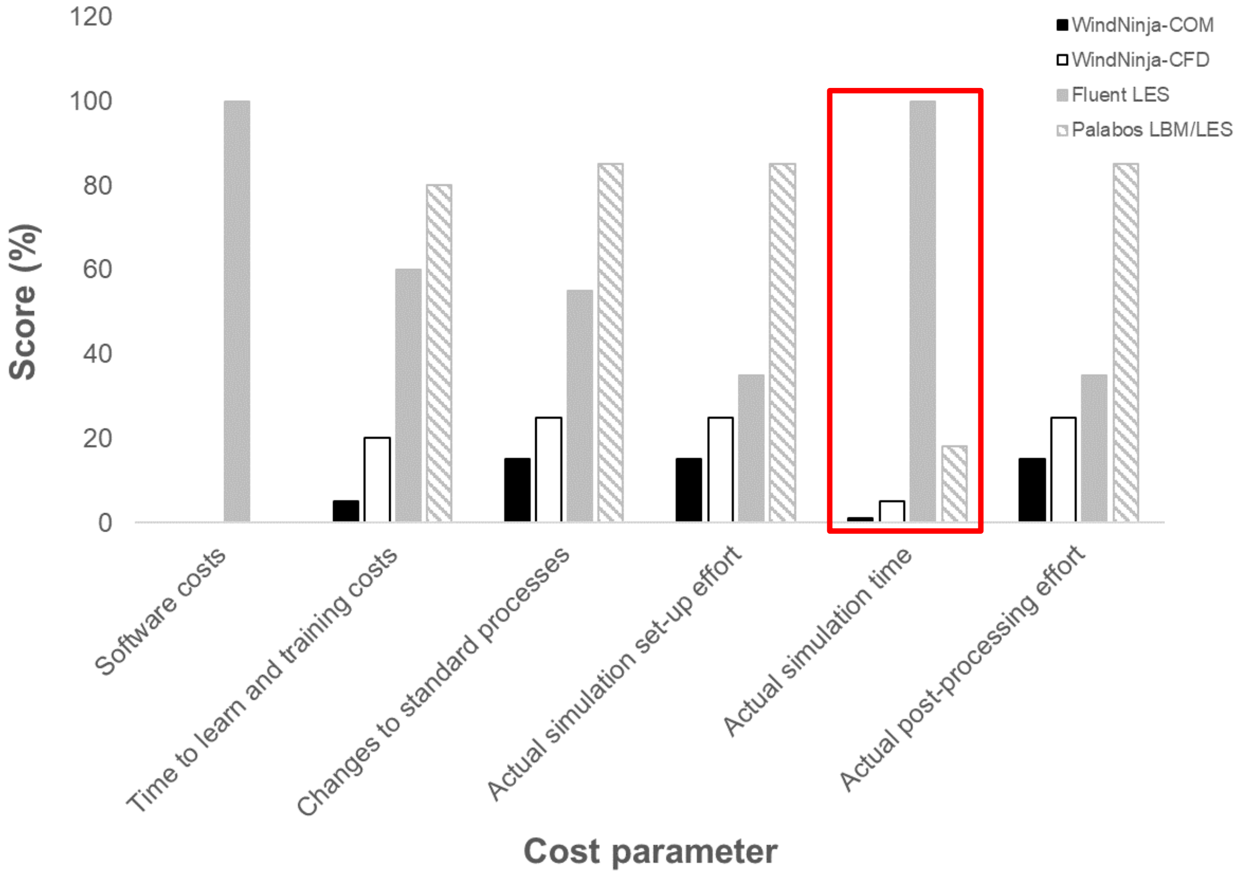


Parameter quantification – cost after

Chosen weighting:



Cost:



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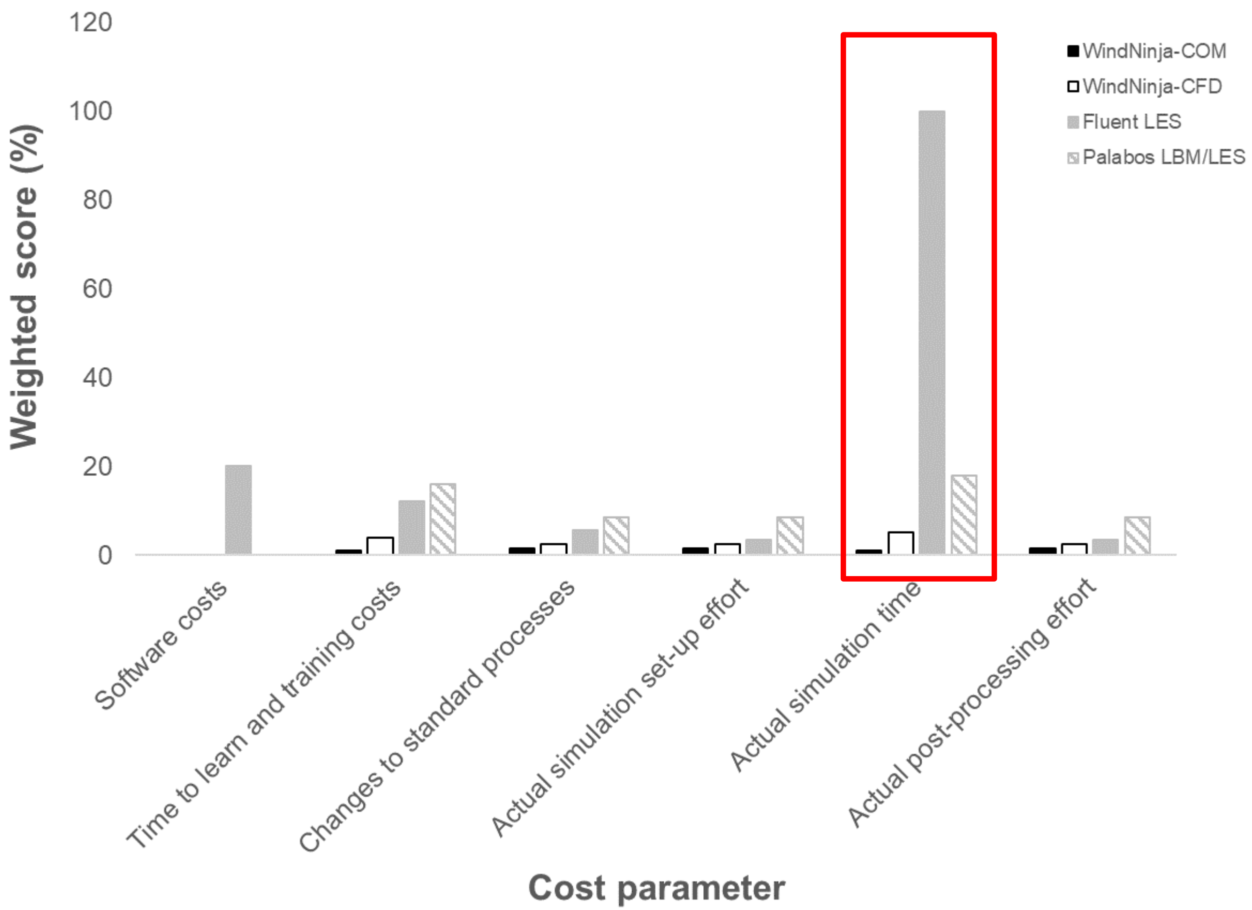
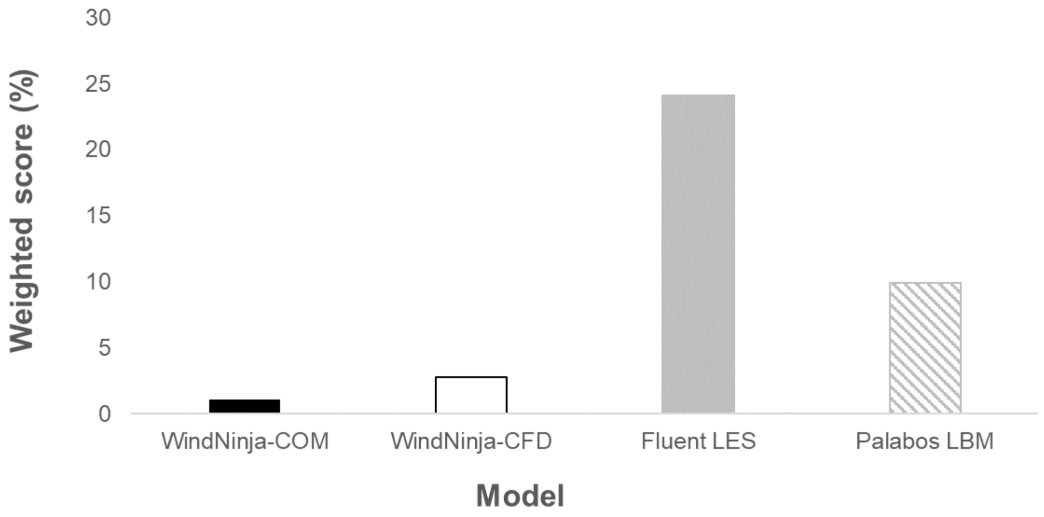
Parameter quantification – cost after

Weighted score:

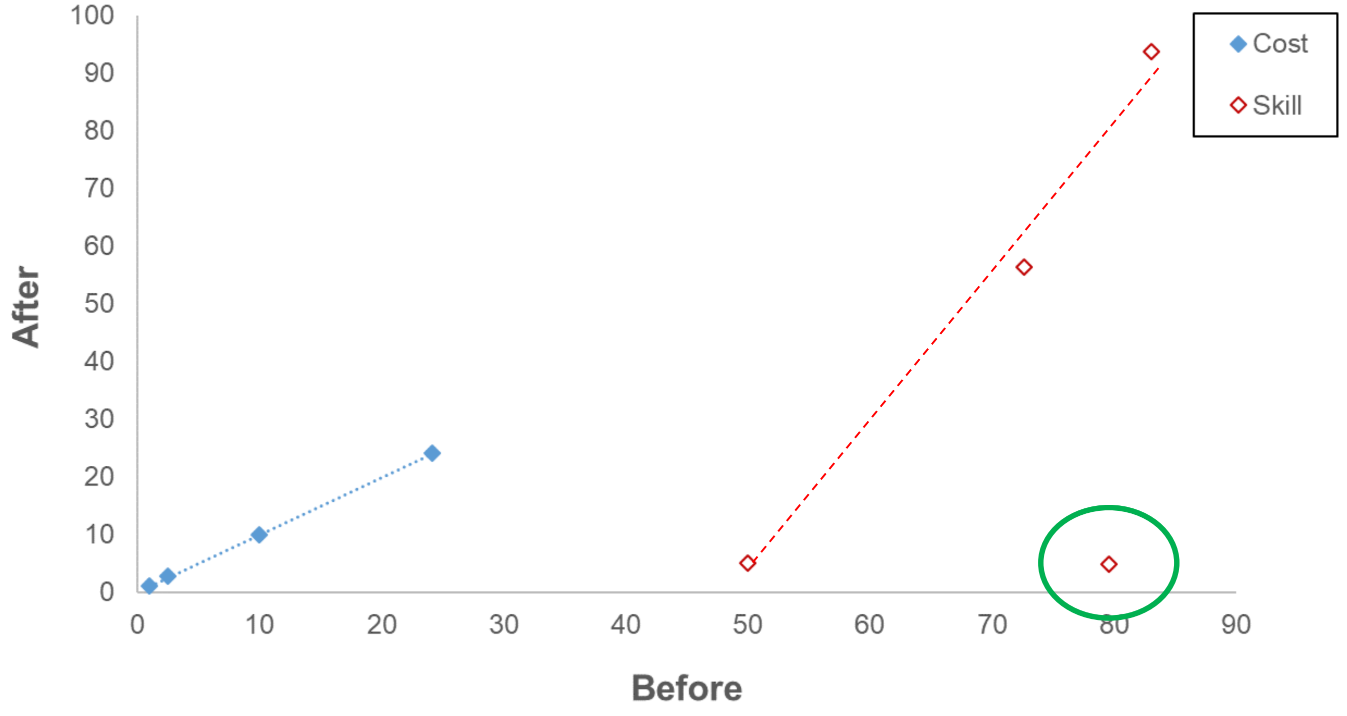


Total scores:



Parameter quantification – comparison before and after

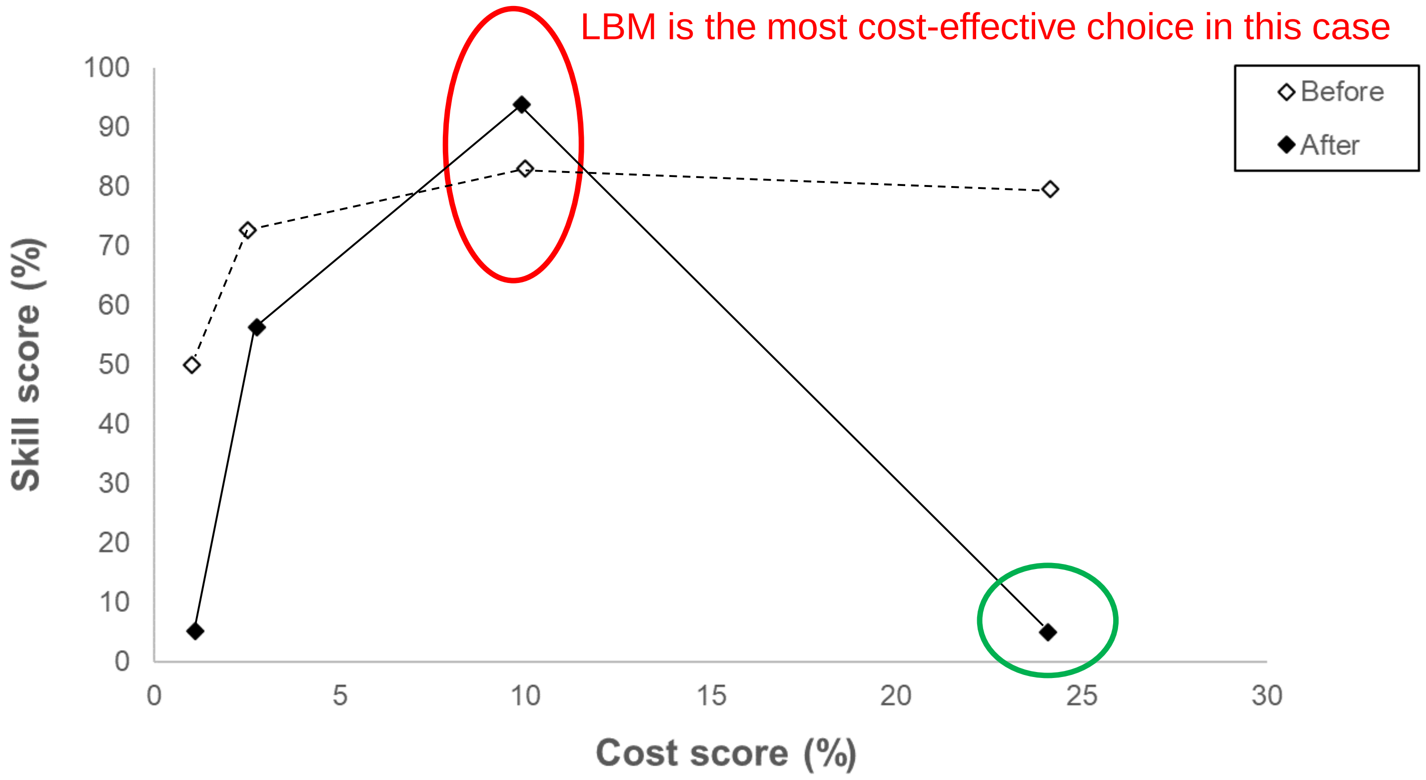
- **"Before" compared to "after":**



- **Cost:**
  - Stayed more or less the same.
  - Differences due to errors in time estimations.
  - Small improvements possible through more studies/experience.
- **Skill:**
  - Large difference in absolute value due to different scaling methods.
  - Trend the same → absolute value not important.
  - Problem with the LES simulations as discussed in previous presentation.

Parameter quantification - comparison

- **Resulting skill vs. cost curve:**

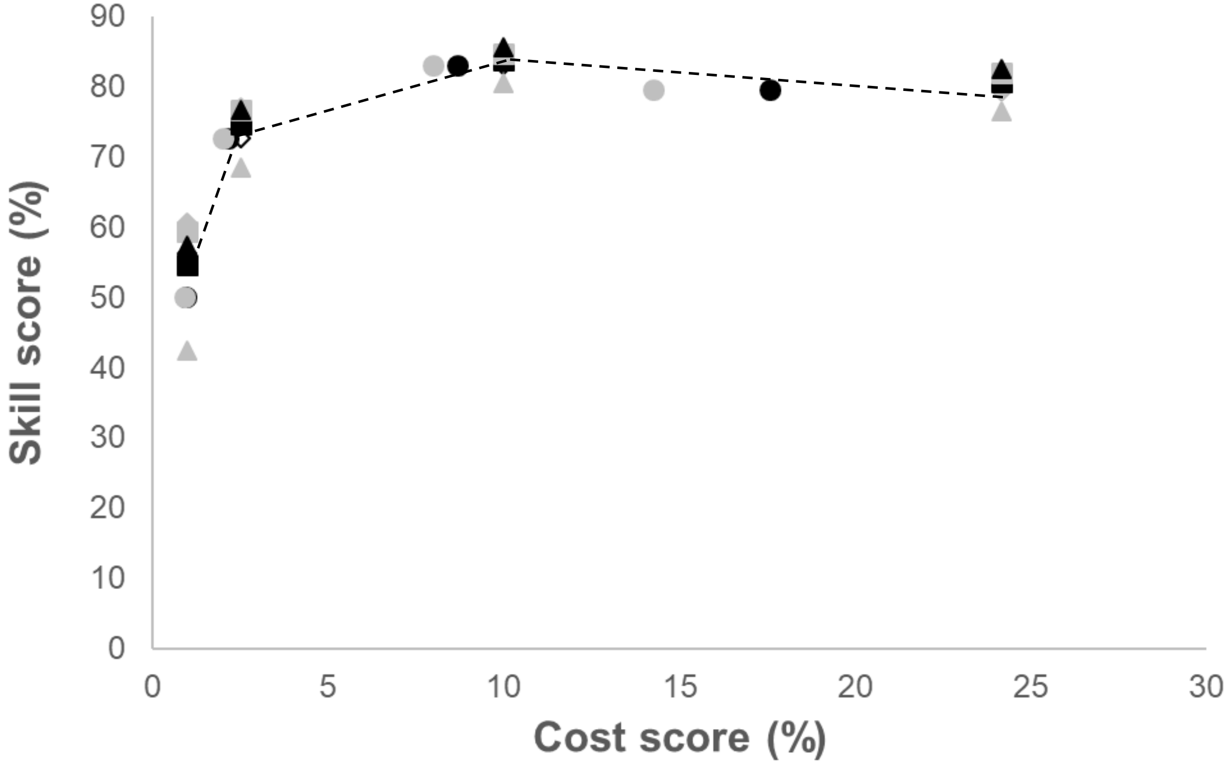


- **Shape the same for "before" and "after", even with Fluent problem.**
  - → Scaling factors need to be investigated.
  - → How to deal with simulation "problems"?
- **Break-even point the same for "before" and "after"**
  - → LBM is the most efficient.
- **Large uncertainties in some parameters**
  - → Further investigations necessary.

Sensitivity study

- **Effect of changing weighting for all four models (for the four most important parameters "before"):**

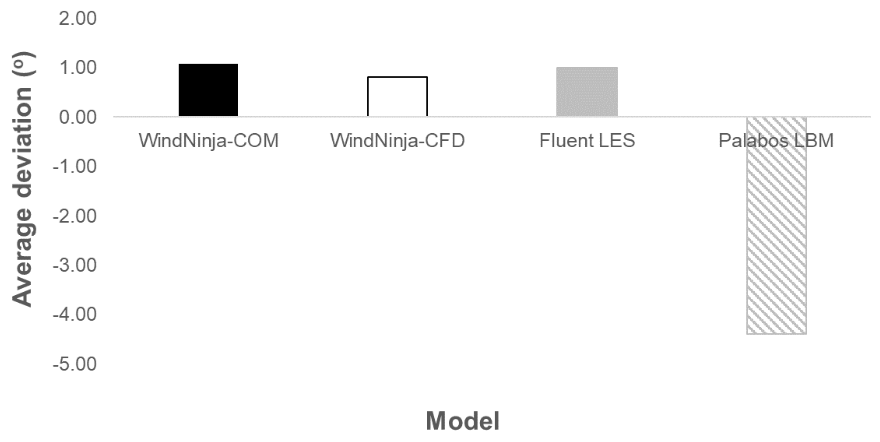
Parameter	Original value	New values
Expected simulation time	◇ 0 100	● 1 60 ● 2 40
Aerodynamic assumptions	◇ 0 100	◆ 3 60 ◆ 4 40
Quality of terrain data	◇ 0 10	■ 5 40 ■ 6 80
Quality of measurement data	◇ 0 40	▲ 7 80 ▲ 8 10



→Shape stays the same.
→More studies needed!

Further work

- **Include other skill parameters: deviation in wind direction, shear factor, turbulence intensity (with appropriate weightings).**
- **Example: average deviation in flow angle doesn't correspond to wind speed behaviour:**



- **Improve the quantification of the parameters where possible.**
  - E.g. complex terrain, set-up time and costs.
- **Expand to Annual Energy Production and financial parameters.**
- **Gather data from wind energy community for lots of other tools (????).**

Conclusions

- **An initial study was undertaken on the quantification of "costs" and "skill" for four wind models for the Bolund Hill test case.**
- **Several parameters for quantifying the "cost" and "skill" were defined for "before" and "after" carrying out the simulations.**
- **The results showed that the "before" parameters could be used reasonably well to choose the most cost-effective model.**
- **The quantification of the scores as well as their weightings need to be further investigated.**

Thank you!

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