

# From Single- to Multi-tower: What is the Optimum Transition Size?

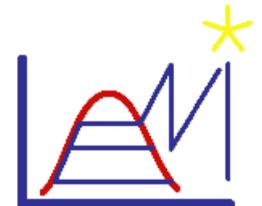
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*SolarPACES - Marrakech, Morocco, 12.09.2012*

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EPFL, Switzerland*



ÉCOLE POLYTECHNIQUE  
FÉDÉRALE DE LAUSANNE

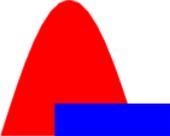


# Outline

1. Context & motivations
2. Multi-tower layouts
3. Receiver selection
4. Single- vs multi-tower
5. Variables sensitivity
6. Thermo-economic optimisation
7. Optimum transition
8. Conclusions & outlook

# 1. Context & motivations (1)

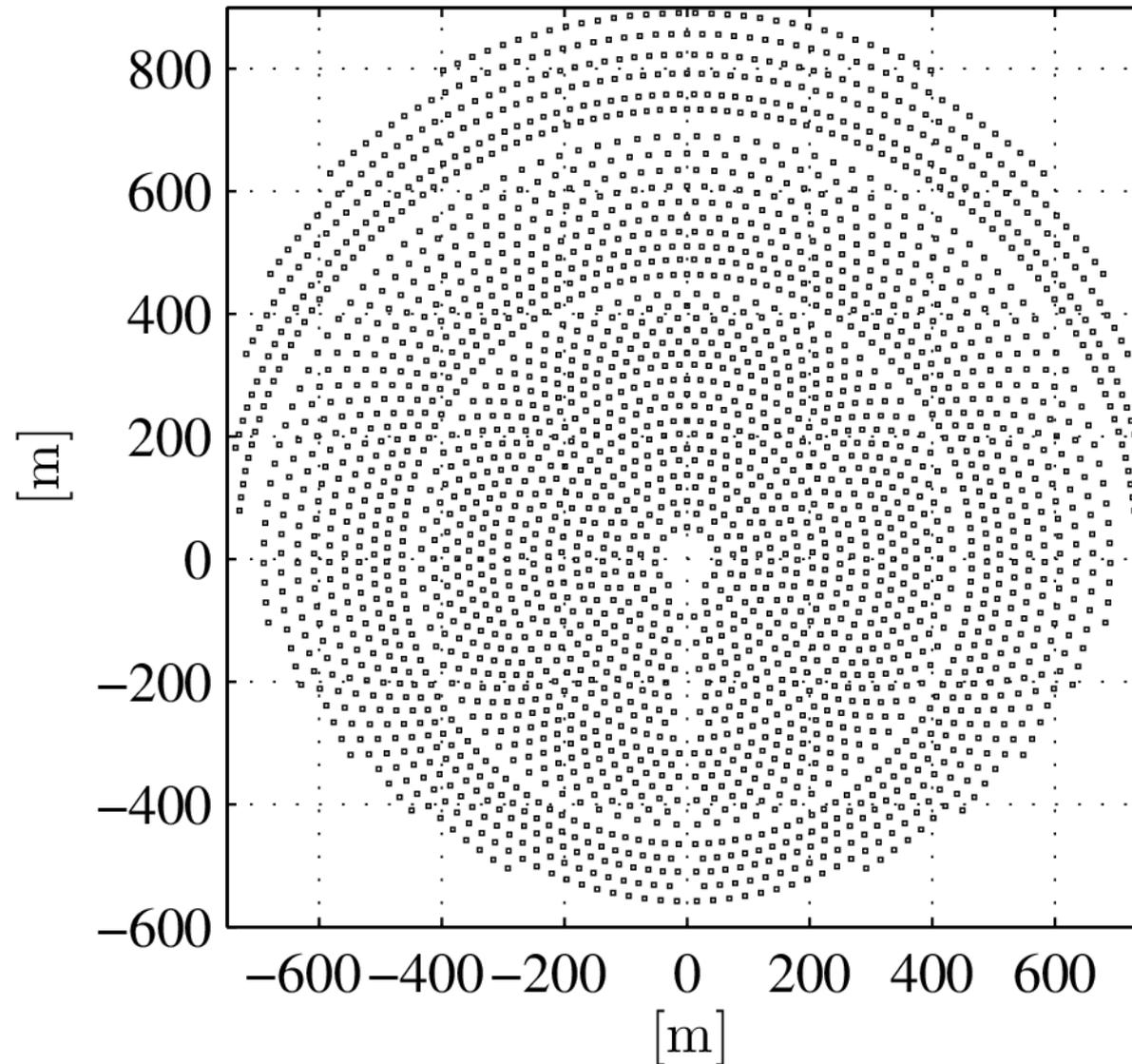
- Large solar tower thermal power plants built to this day:

<i>Description</i>	<i>Annual DNI</i> [kWh/m <sup>2</sup> /y]	<i>Refl. area</i> [m <sup>2</sup> ]	<i>Tower height</i> [m]	<i>Rec. / Gen. pow.</i> [MW <sub>th</sub> ] / [MW <sub>el</sub> ]
PS20	2'441 	150'600 	165 	-/20.0 
Gemasolar	2'432 	318'000 	140 	120.0/19.9 
Ivanpah	2'646 	1'408'000 	140 	-/126.0 

# 1. Context & motivations (2)

- Interest of multi-tower set-ups?
- If yes, from what field size?

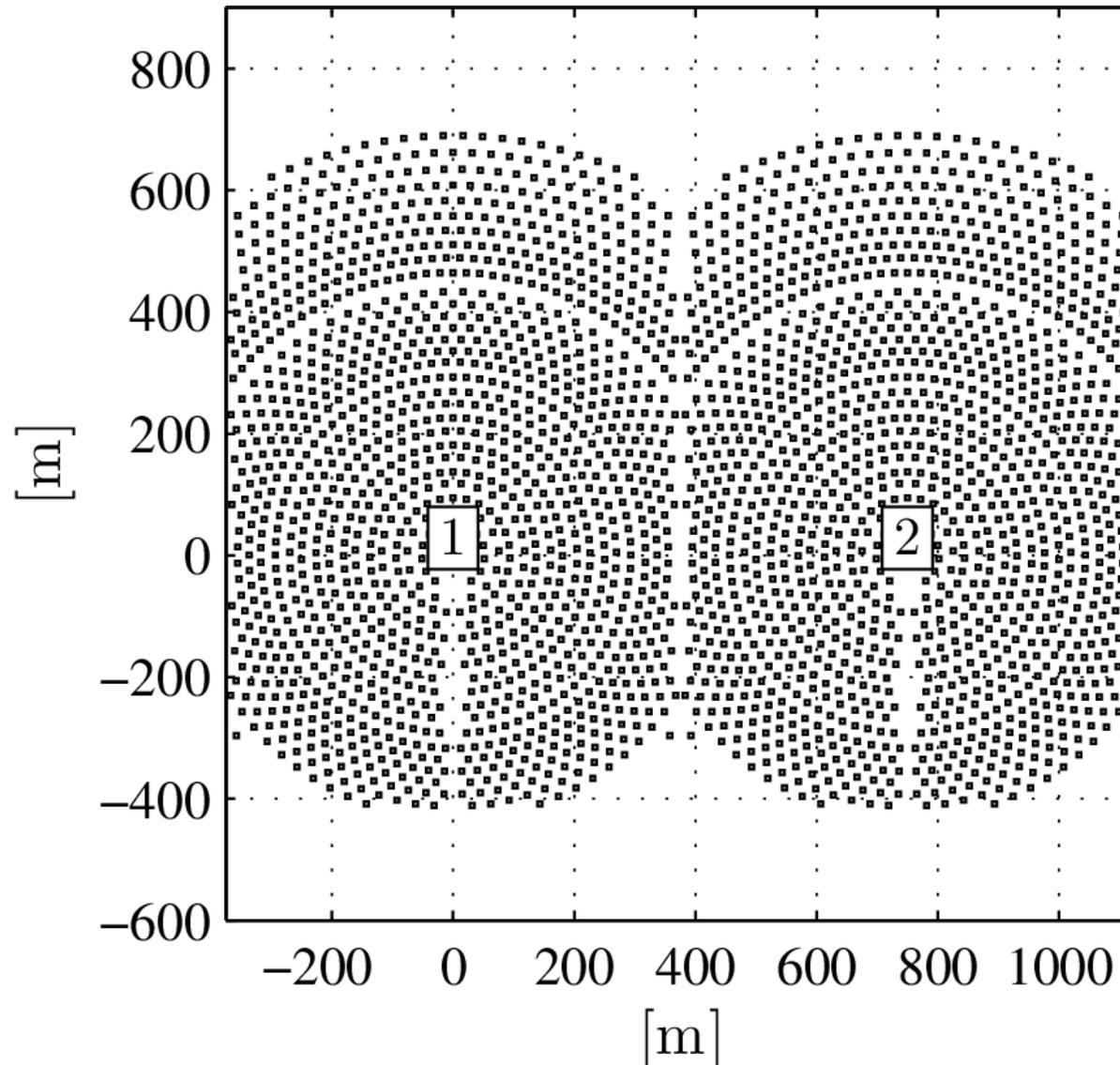
## 2. Multi-tower layouts (1)



1 tower

(2650 heliostats,  
Gemasolar-like)

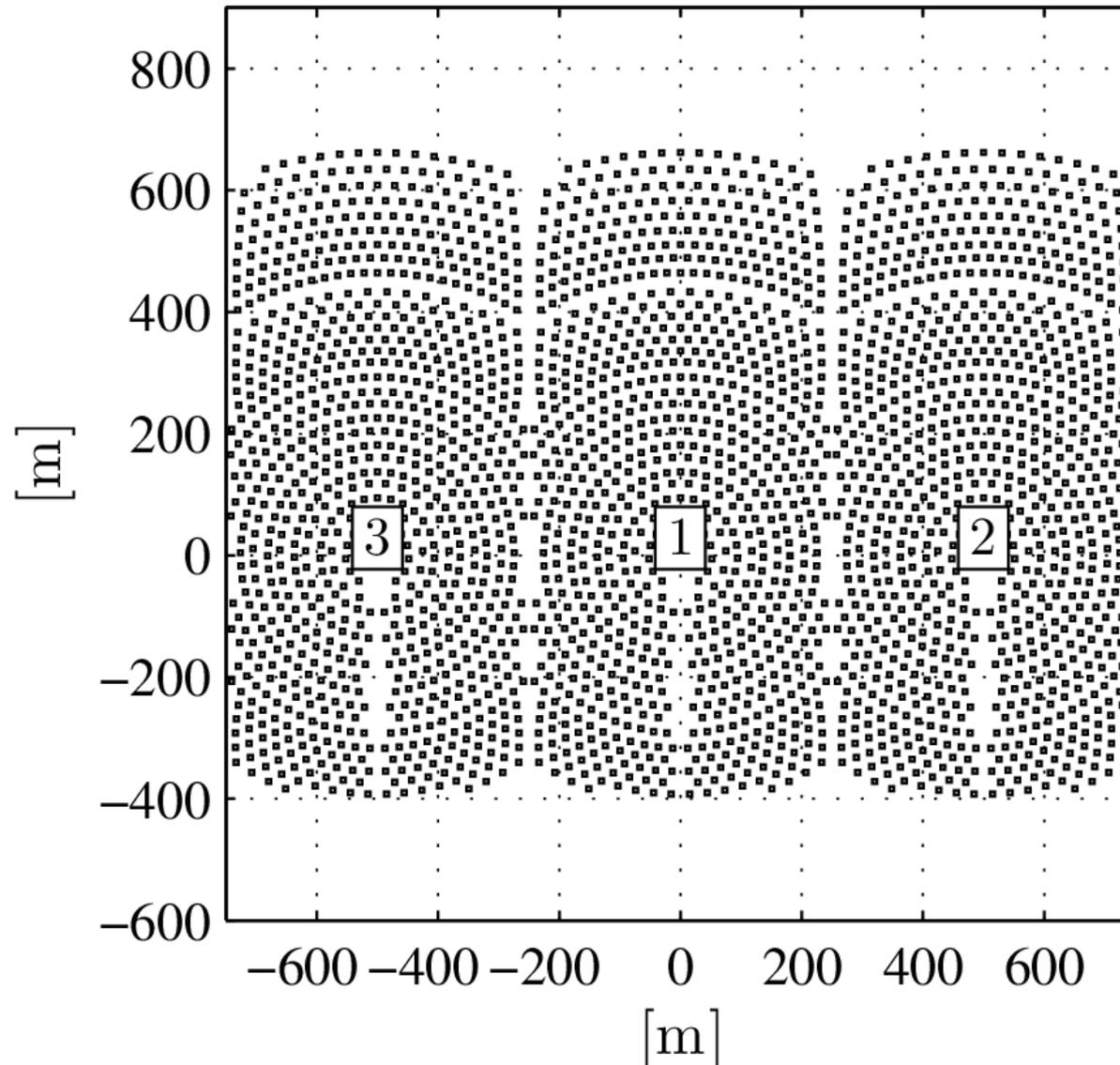
## 2. Multi-tower layouts (2)



2 towers

(2650 heliostats,  
distance 750 [m])

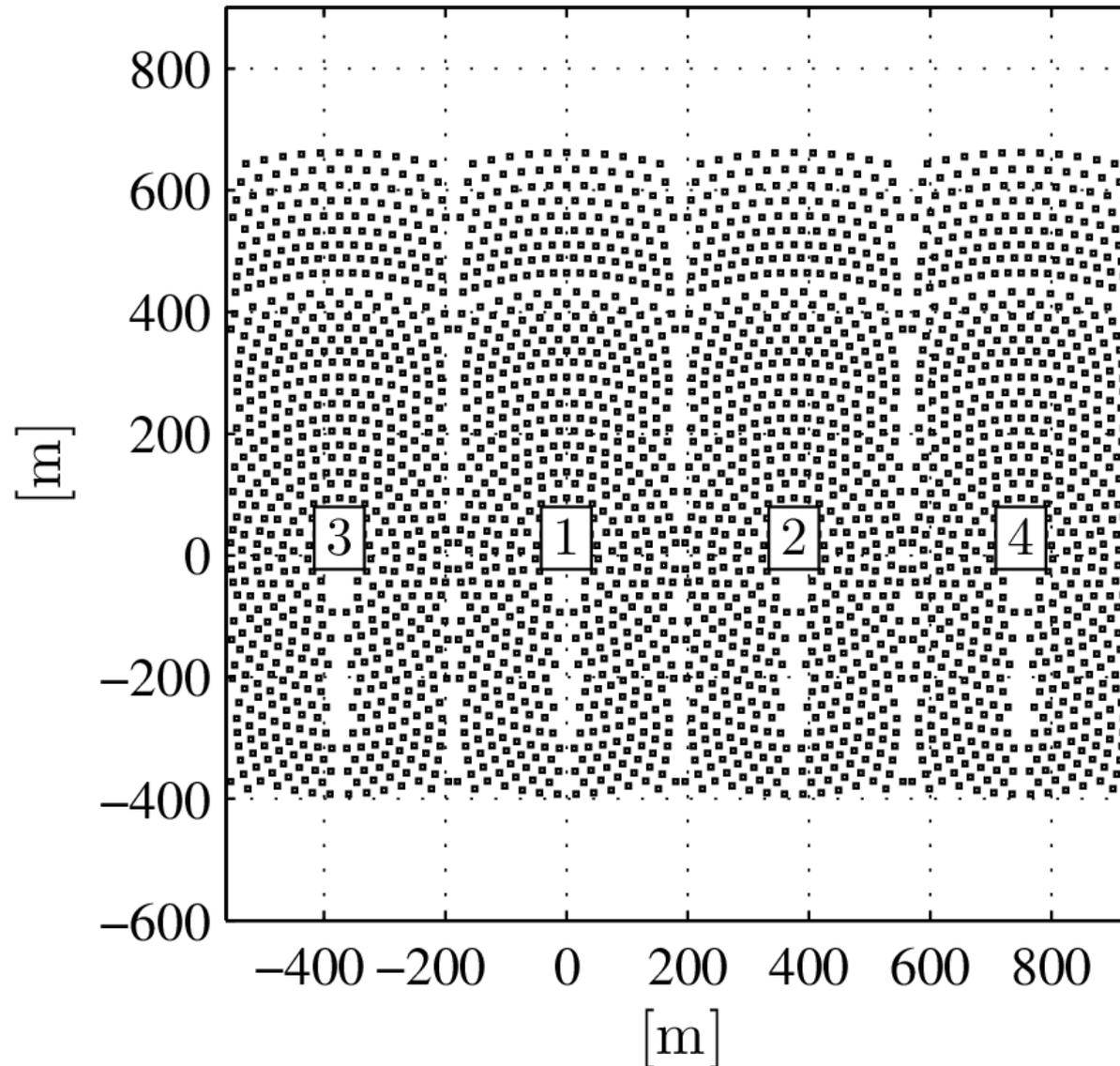
## 2. Multi-tower layouts (3)



3 towers

(2650 heliostats,  
distance 500 [m])

## 2. Multi-tower layouts (4)

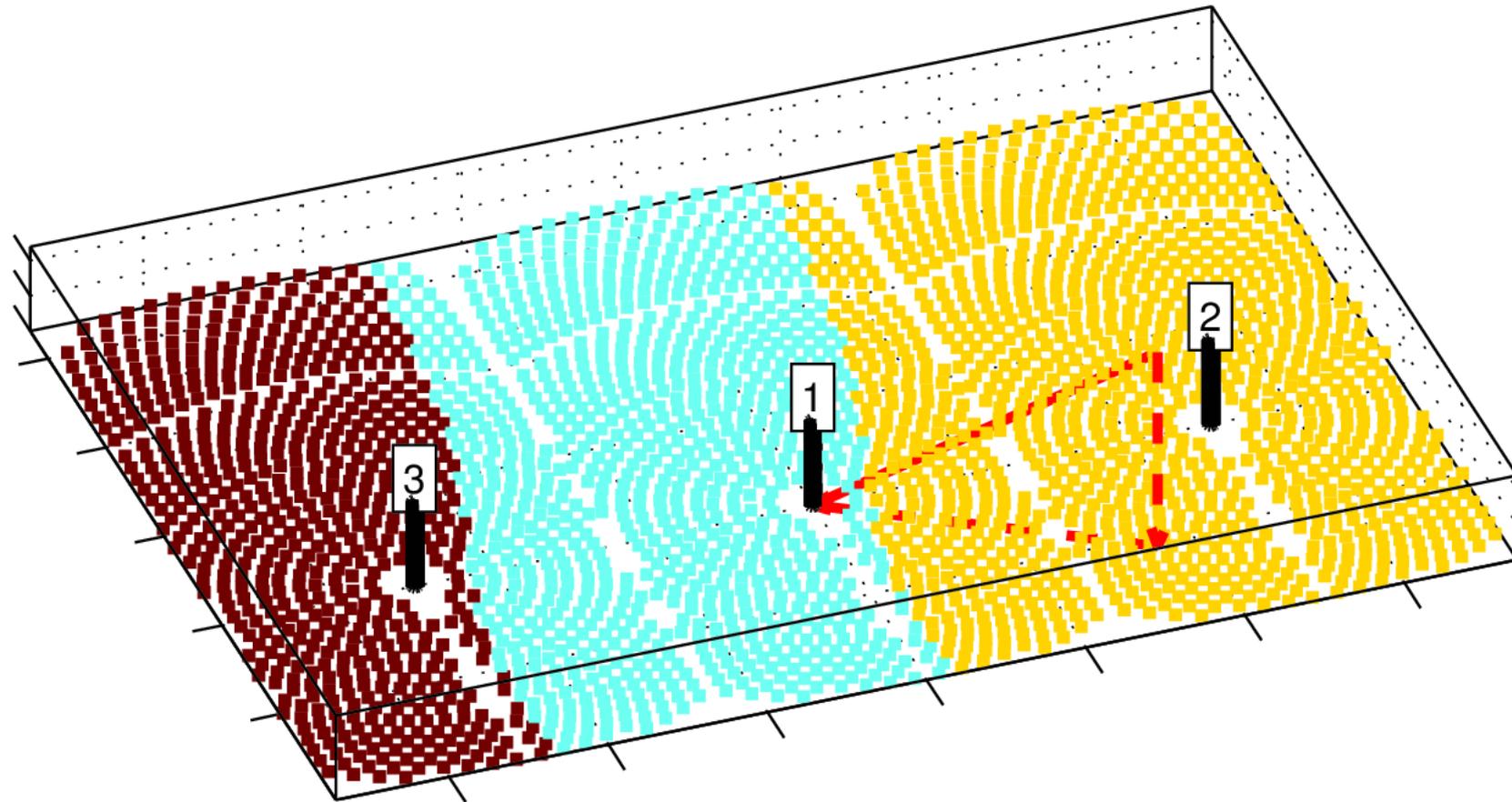


4 towers

(2650 heliostats,  
distance 375 [m])

# 3. Receiver selection (1)

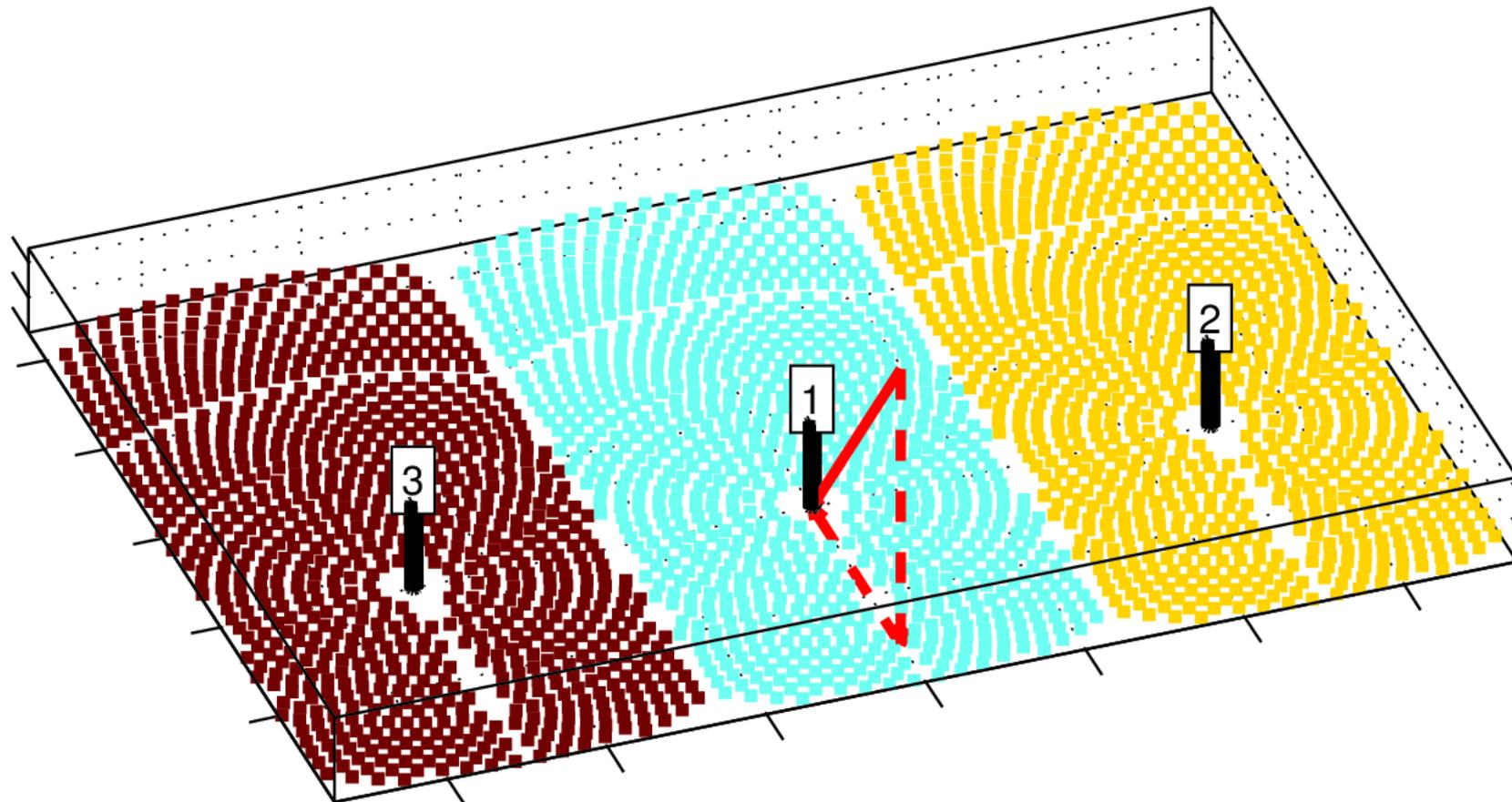
Criterion: min. cosine+atmospheric+spillage loss



20/03  
09:00 ST

# 3. Receiver selection (2)

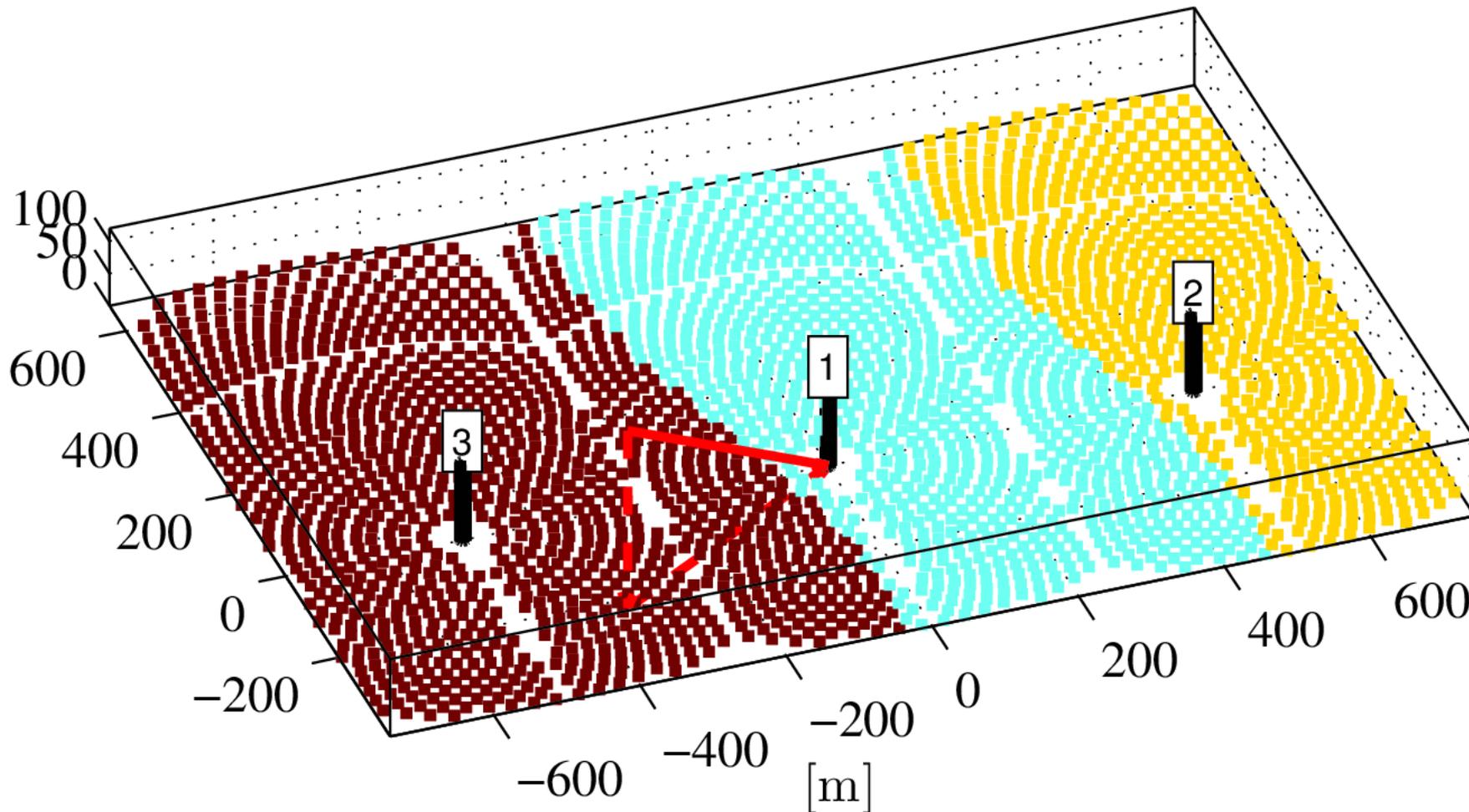
Criterion: min. cosine+atmospheric+spillage loss



20/03  
12:00 ST

# 3. Receiver selection (3)

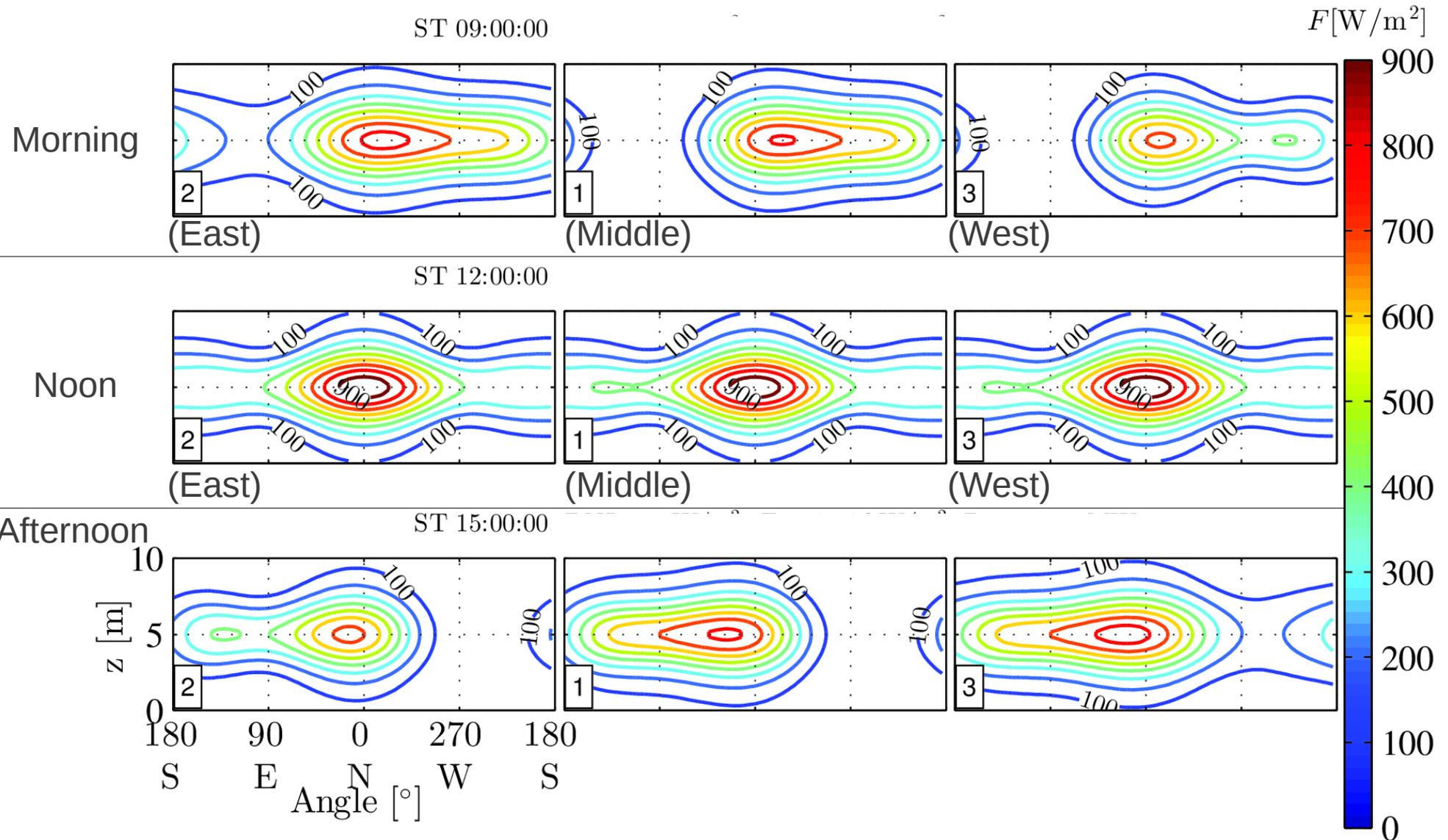
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20/03  
15:00 ST

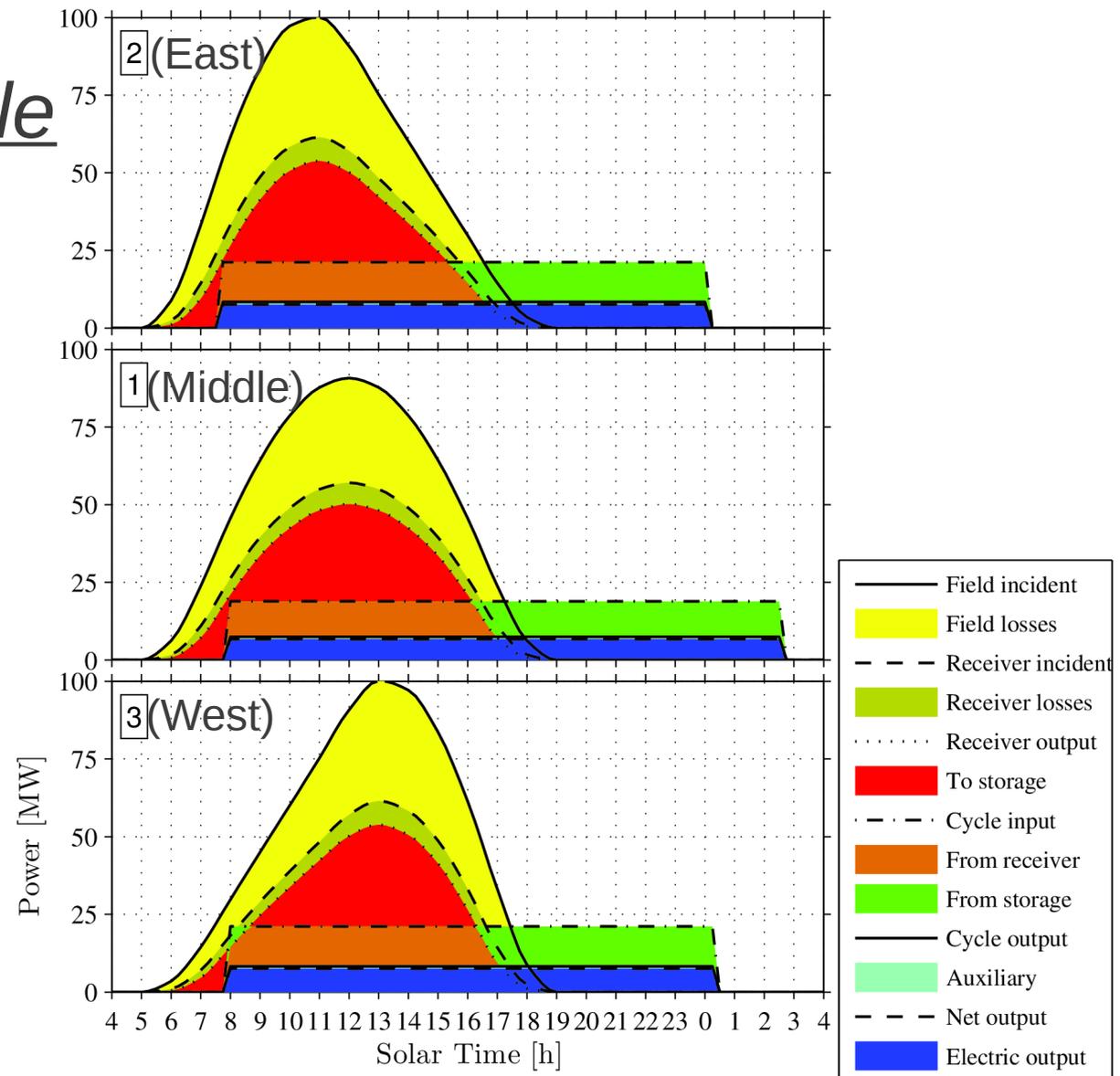
# 3. Receiver selection (4)

## Receivers heat flux



# 3. Receiver selection (5)

## Operation profile



# 4. Single- vs multi-tower

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<i>Set-up</i>			
Number of heliostats	2650	2650	[u]
Number of receivers	1	3	[u]

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<i>Energy performance</i>			
Annual field efficiency	45.3	59.8	[%]
Max. receiver incident power	138.2	179.2	[MW <sub>th</sub> ]

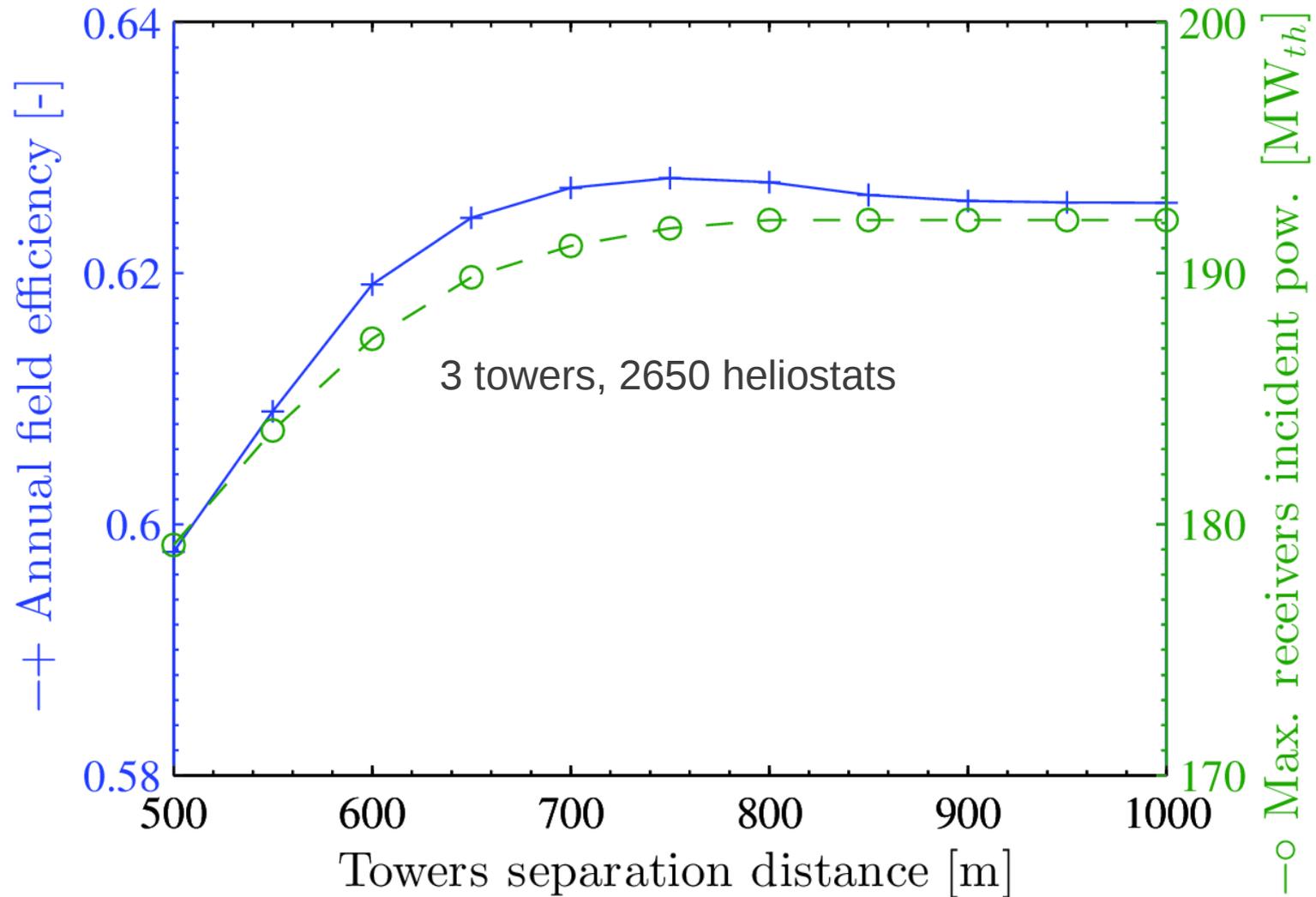
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<i>Economic performance</i>			
Simulated cost	150.5	256.6	[M\$]
Levelised electricity cost	24.1	29.7	[¢/kWh <sub>el</sub> ]

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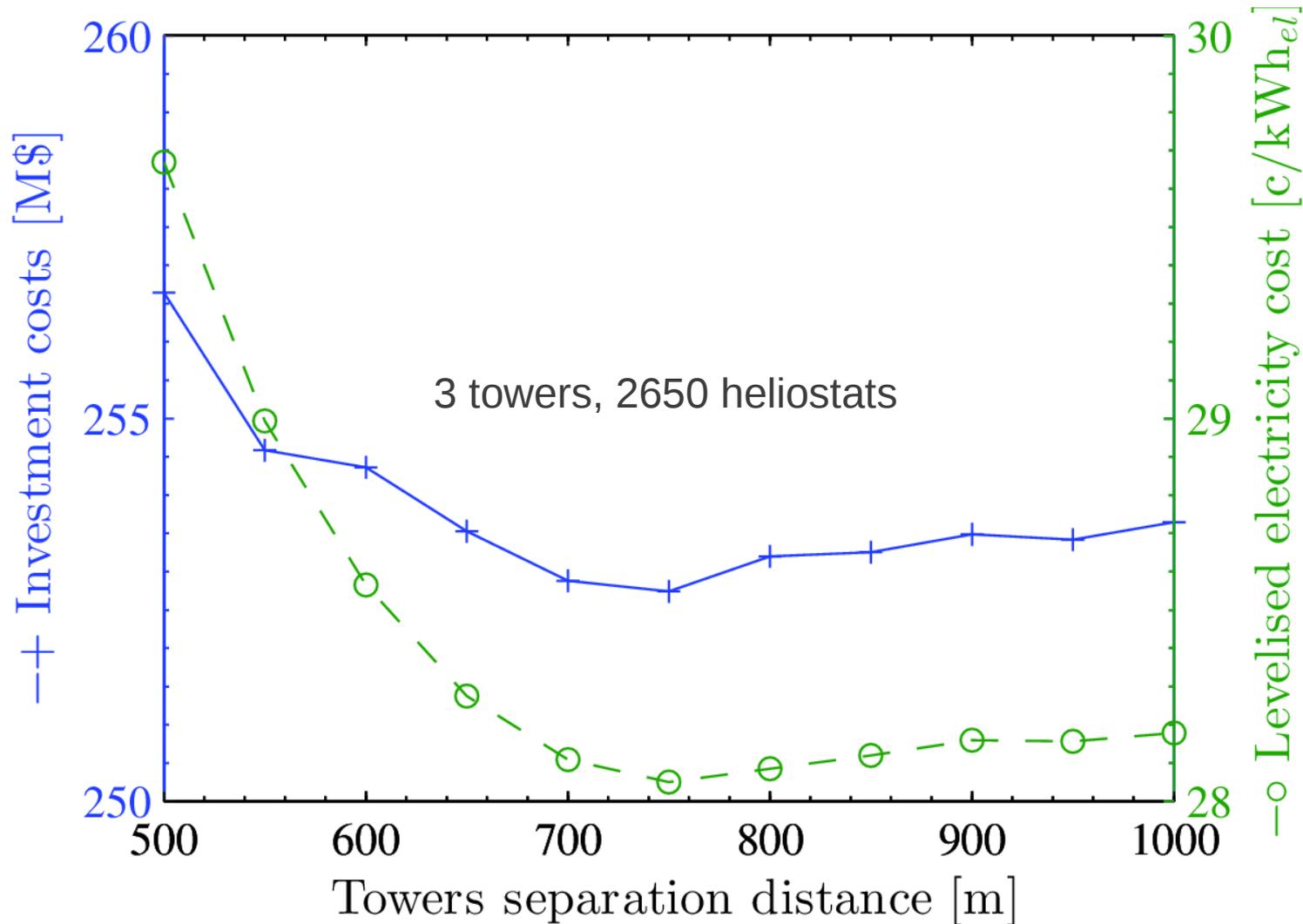
# 5. Variables sensitivity (1)

## Energy performance vs. towers distance



# 5. Variables sensitivity (2)

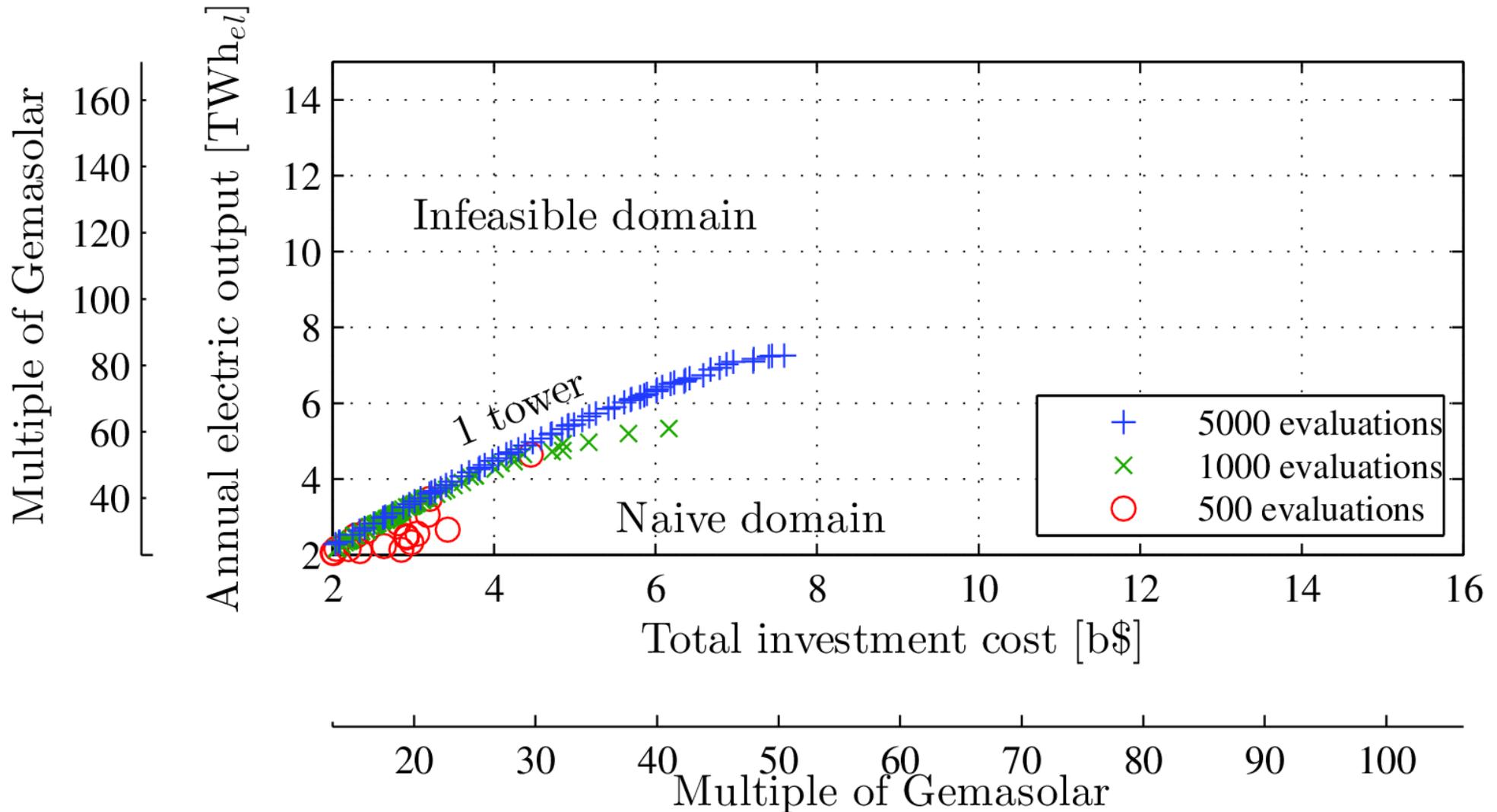
## Economic performance vs. towers distance



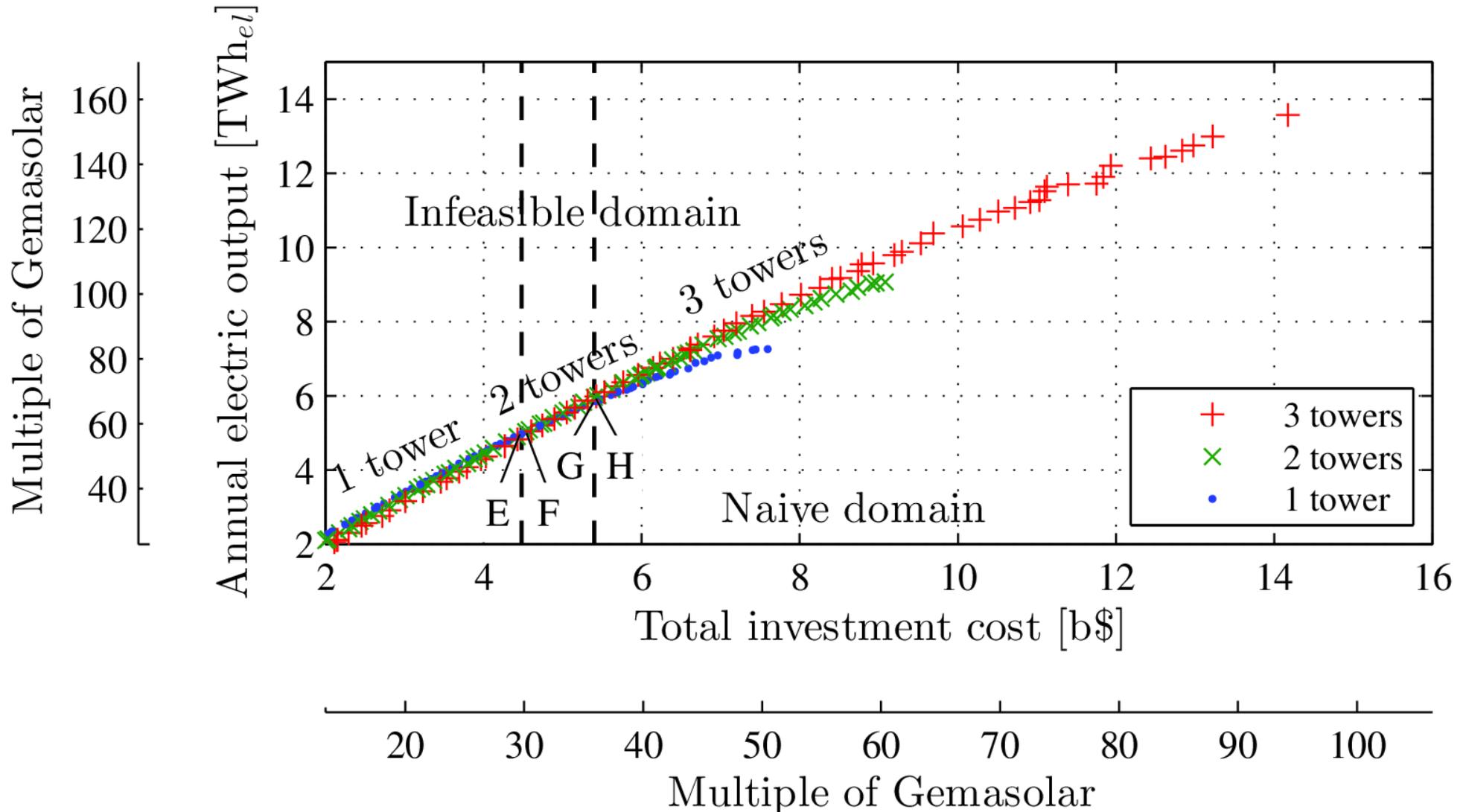
# 6. Thermo-economic optimisation(1)

<i>Decision variables</i>	Range	Unit
Heliostat width	1-30	[m]
Heliostat height	1-30	[m]
Number of heliostats	100-100'000	[u]
Towers height	1-1'000	[m]
Receivers diameter	1-100	[m]
Receivers height	1-100	[m]
<i>Contradictory objectives</i>		
Total investment cost	min.	[\$]
Annual electricity output	max.	[Wh <sub>el</sub> ]
<i>Constraints</i>		
Receiver heat flux peak	< 1500	[kW <sub>th</sub> /m <sup>2</sup> ]

# 6. Thermo-economic optimisation(2)



# 7. Optimum transition (1)

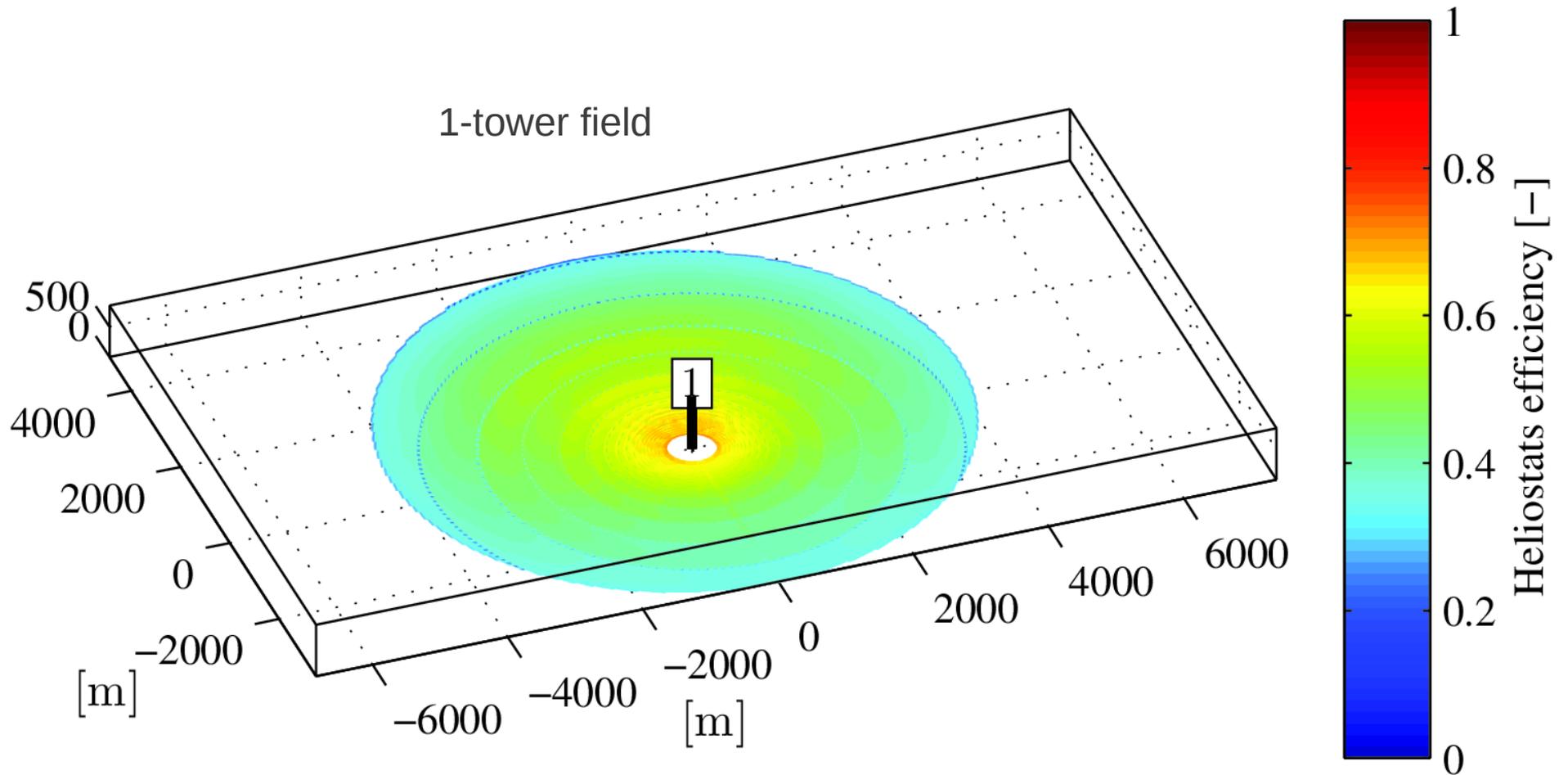


# 7. Optimum transition (2)

<i>Design variables</i>	Transition 1 to 2 towers		2 to 3 towers		<i>Units</i>
	<i>E</i>	<i>F</i>	<i>G</i>	<i>H</i>	
Number of towers	1	2	2	3	[u]
Reflective area	17.9	16.2	19.6	18.6	[mil. m <sup>2</sup> ]
<i>Energy performance</i>					
Annual field efficiency	0.46	0.52	0.51	0.53	[-]
Max. receiver incident power	8.14	8.24	9.81	9.74	[GW <sub>th</sub> ]
<i>Economic performance</i>					
Total investment costs	4.48	4.53	5.4	5.43	[b\$]
Levelised electricity cost	15.16	15.17	15.23	15.24	[c/kWh <sub>el</sub> ]

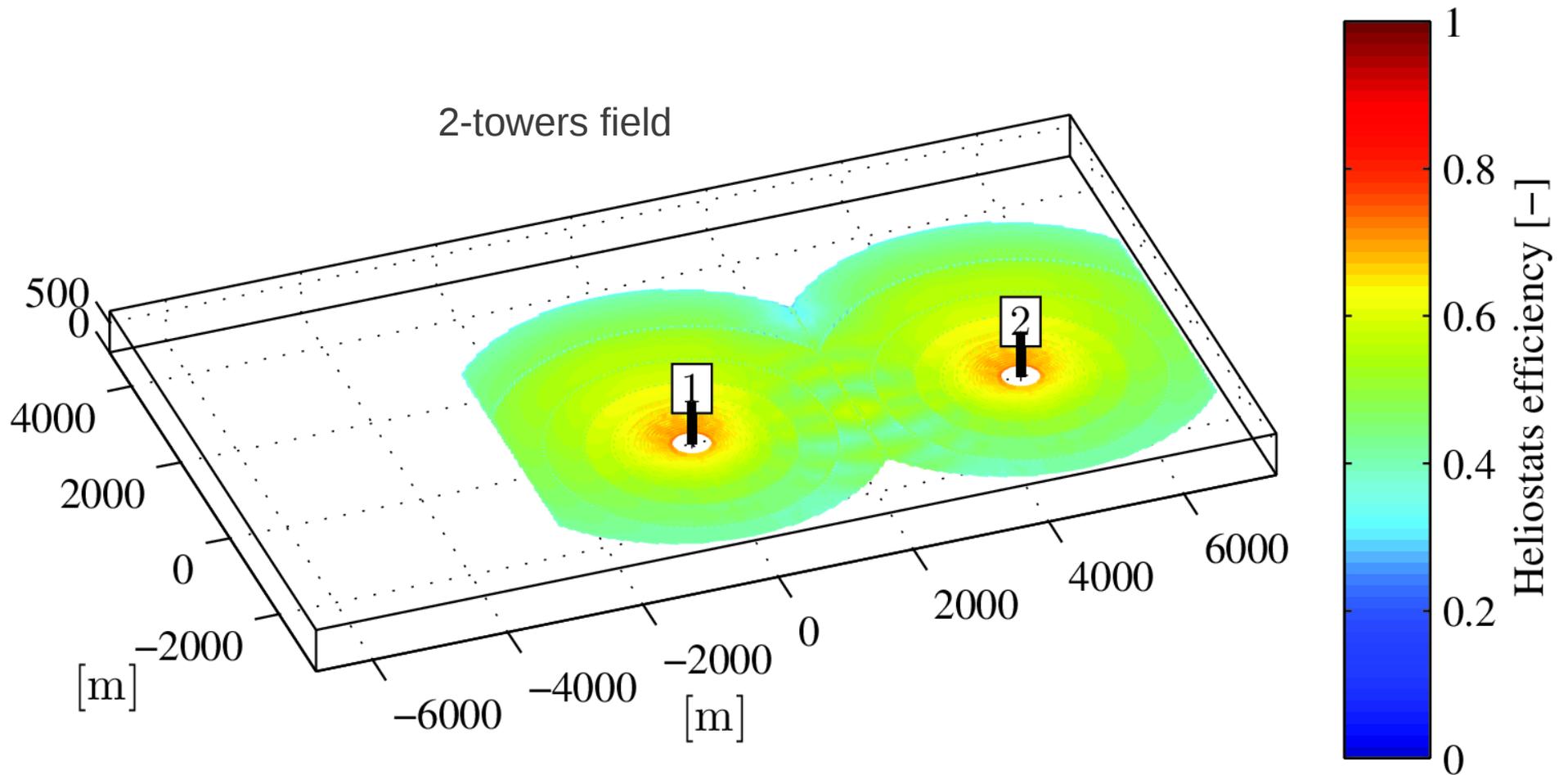
# 7. Optimum transition (3)

## From 1 to 2 towers



# 7. Optimum transition (4)

## From 1 to 2 towers



# 8. Conclusions & outlook

- simple method for the design of multi-tower layouts
- interest identified:
  - efficiency increased significantly (15 points)
  - but costs increased more
- thermo-economic optimisation:
  - optimum transition found
  - so far, costs too high for realistic transition size (30-40xGemastar)

Thank you for your attention

Acknowledgement:  
Alstom Switzerland AG

# References

- [1] Schramek, P., & Mills, D. R. (2003). Multi-tower solar array. *Solar Energy*, 75(3), 249–260.
- [2] Caldwell, D. W. (2009). Multi-receiver heliostat system architecture.
- [3] Siala, F. M., & Elayeb, M. (2001). Mathematical formulation of a graphical method for a no-blocking heliostat field layout. *Renewable Energy*, 23(1), 77–92.
- [4] Burgaleta, J. I., Arias, S., & Ramirez, D. (2011). GEMASOLAR, the First Tower Thermosolar Commercial Plant With Molten Salt Storage. *Proceedings of the SolarPACES 2011 Conference on Concentrating Solar Power and Chemical Energy Systems*. Granada, Spain.
- [5] Augsburger, G., Zhang, H., Jüchli, I., and Pelet, X. (2012). *Lenisolar: a Code for the Thermo-economic Optimisation of Solar Tower Power Plants*. Technical report, Industrial Energy Systems Laboratory, École Polytechnique Fédérale de Lausanne, Bât. ME A2, Station 9, CH - 1015 Lausanne, Vaud, Switzerland.
- [6] Molyneaux, A., Leyland, G., and Favrat, D. (2010). Environomic multi-objective optimisation of a district heating network considering centralized and decentralized heat pumps. *Energy*, 35(2):751–758.

# Backup

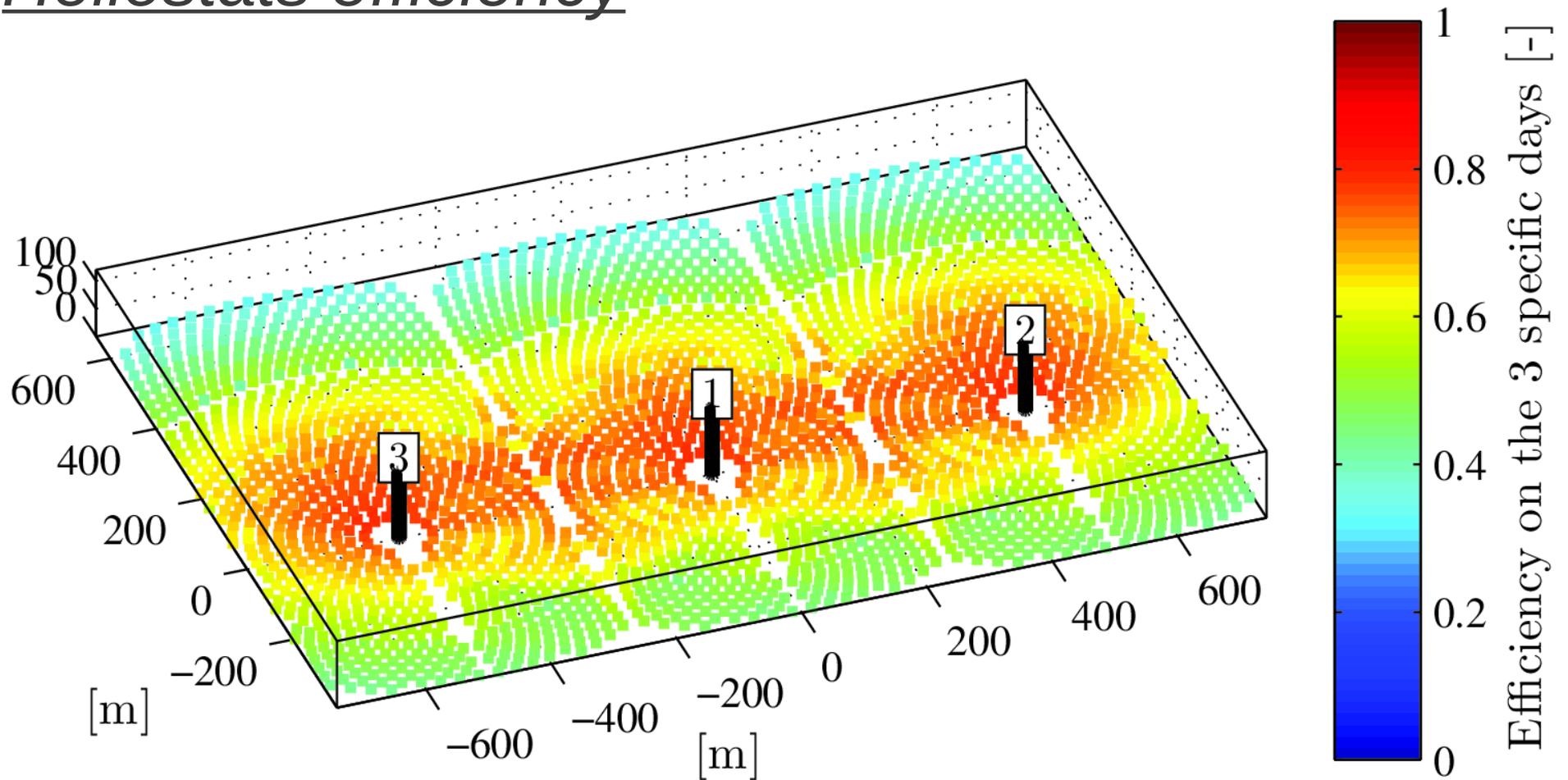
# 1. Context & motivations

- Large solar tower thermal power plants built to this day:

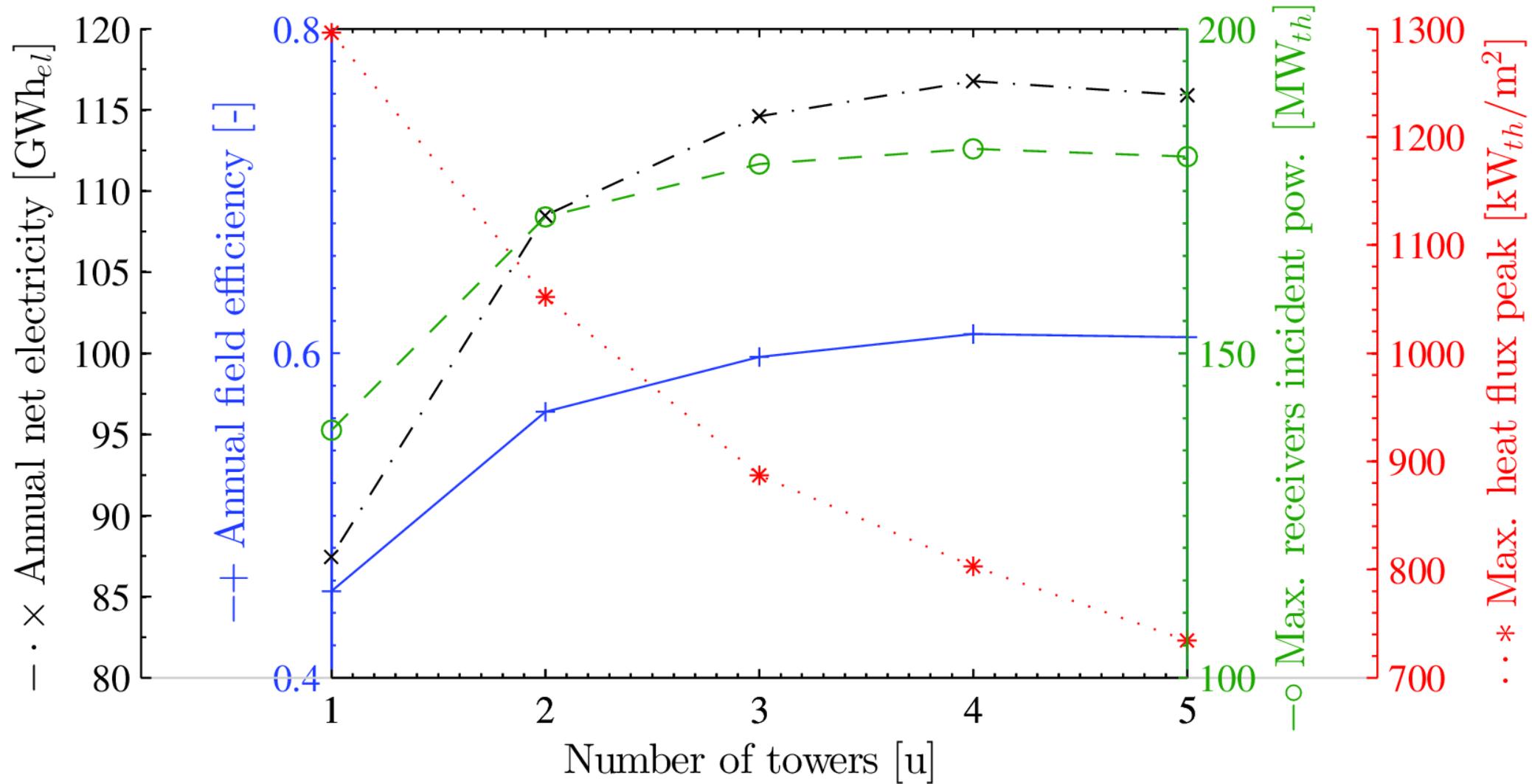
<i>Description</i>	<i>Annual DNI</i> [kWh/m <sup>2</sup> /y]	<i>Refl. area</i> [m <sup>2</sup> ]	<i>Tower height</i> [m]	<i>Rec. / Gen. pow.</i> [MW <sub>th</sub> ] / [MW <sub>el</sub> ]
Sierra SunTower	2'646 	27'264 	55 	-/5.0 
Coalinga	2'281 	59'653 	100 	29.0/eq.13.0 
PS10	2'439 	74'880 	115 	47.7/11.0 

# 3. Receiver selection (5)

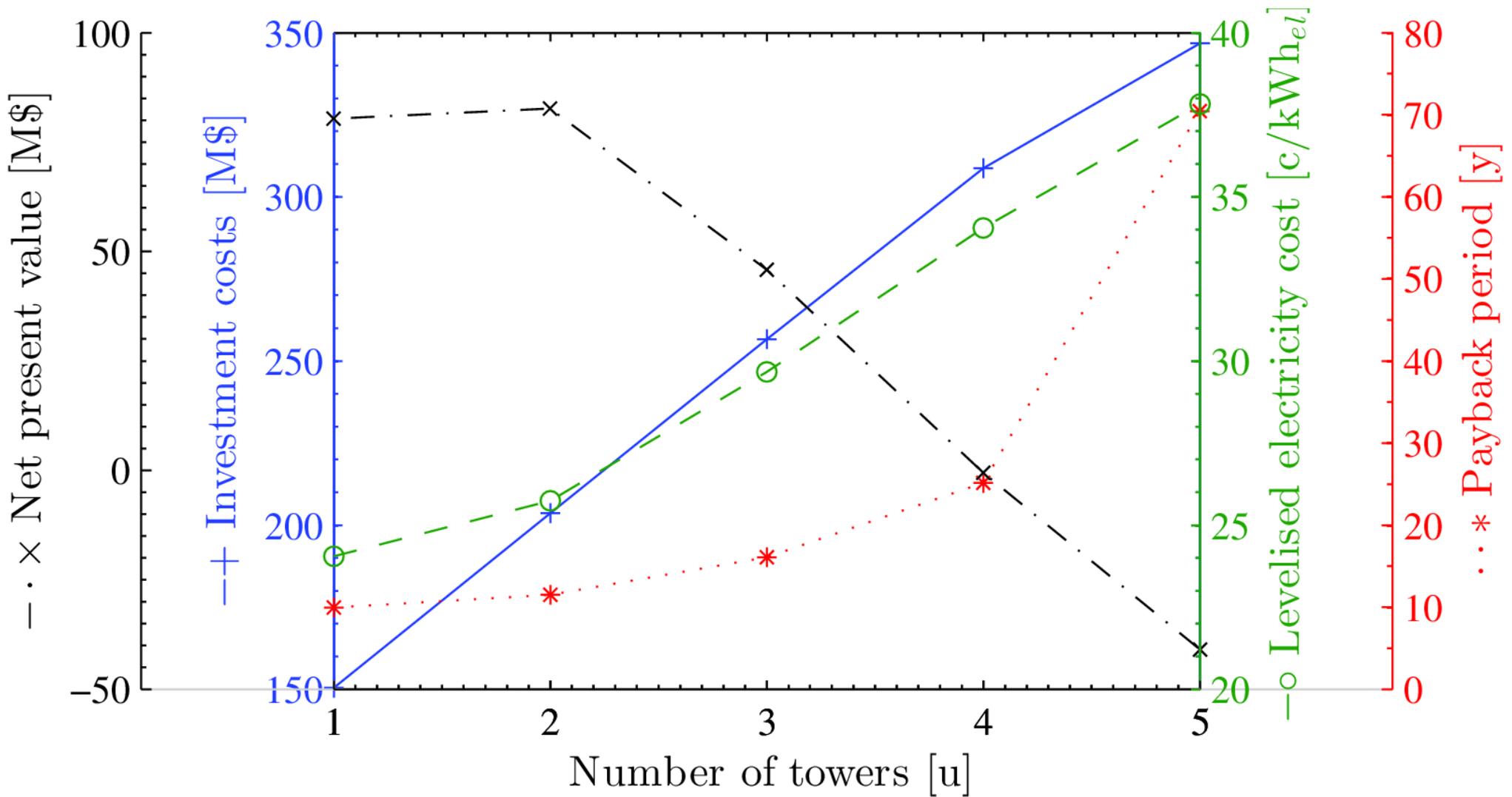
## Heliostats efficiency



# Variables sensitivity

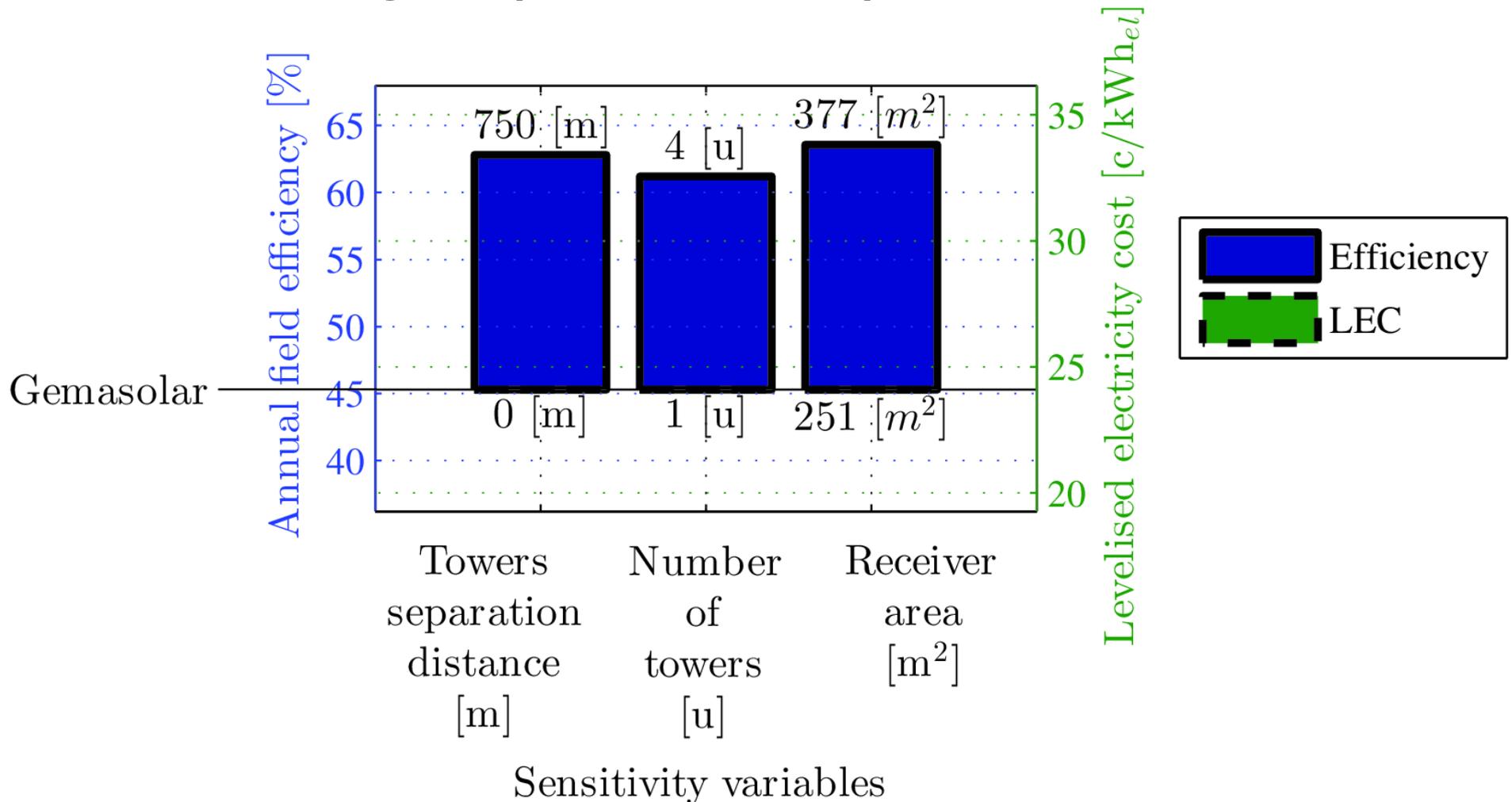


# Variables sensitivity



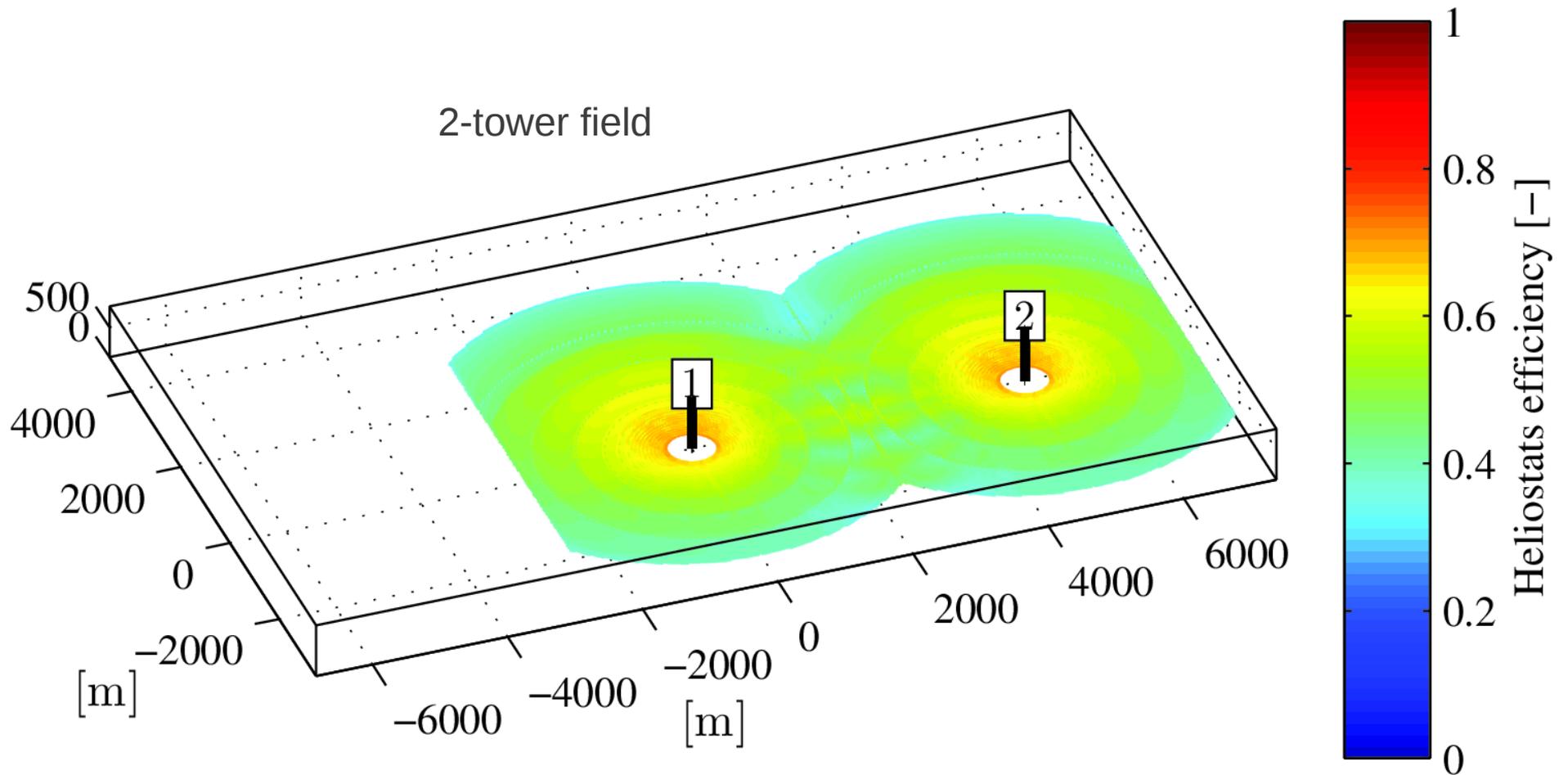
# 5. Variables sensitivity

## 5.3. Summary of potential improvements



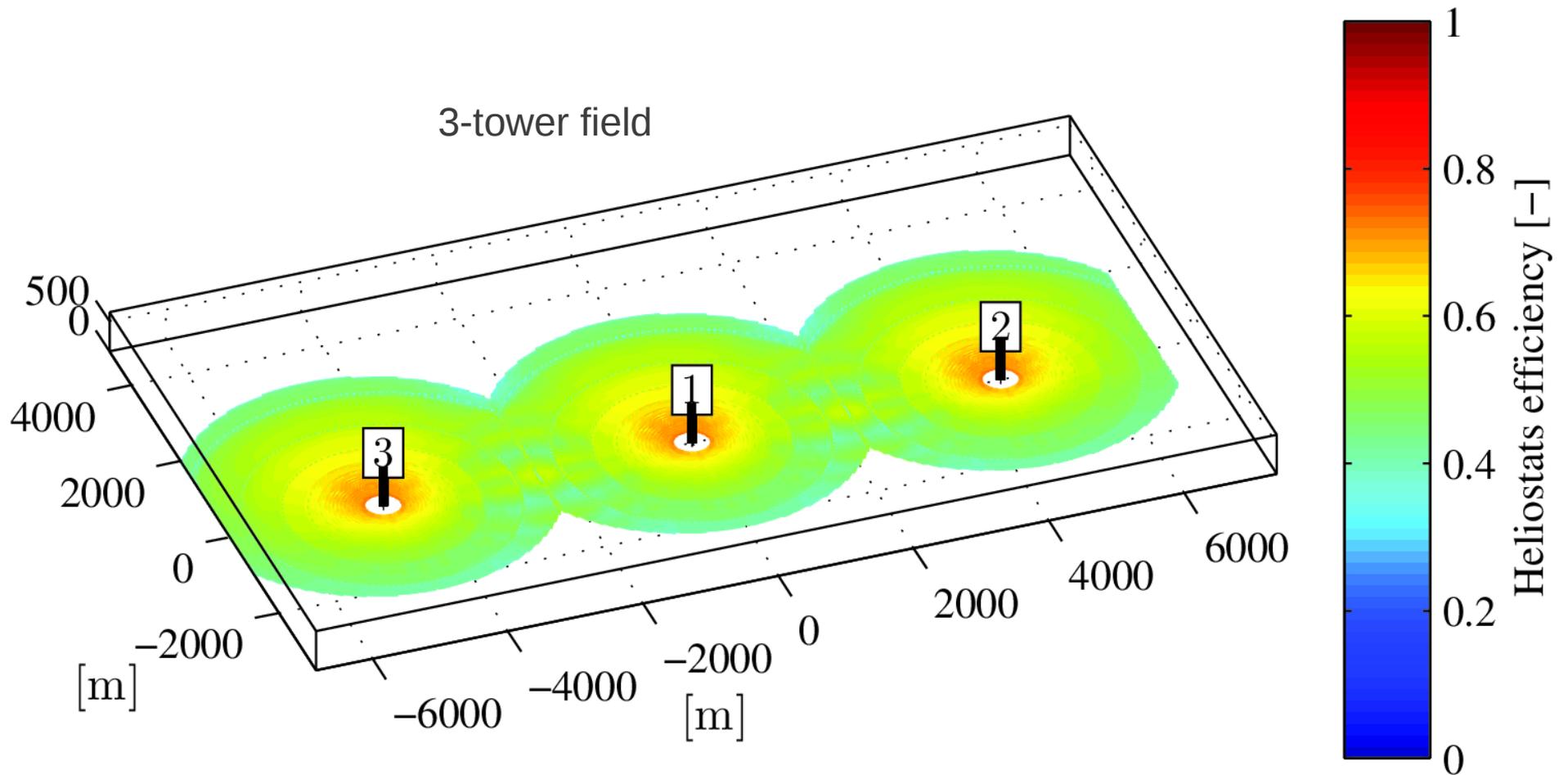
# 7. Optimum transition

## 7.2. From 2 to 3 towers

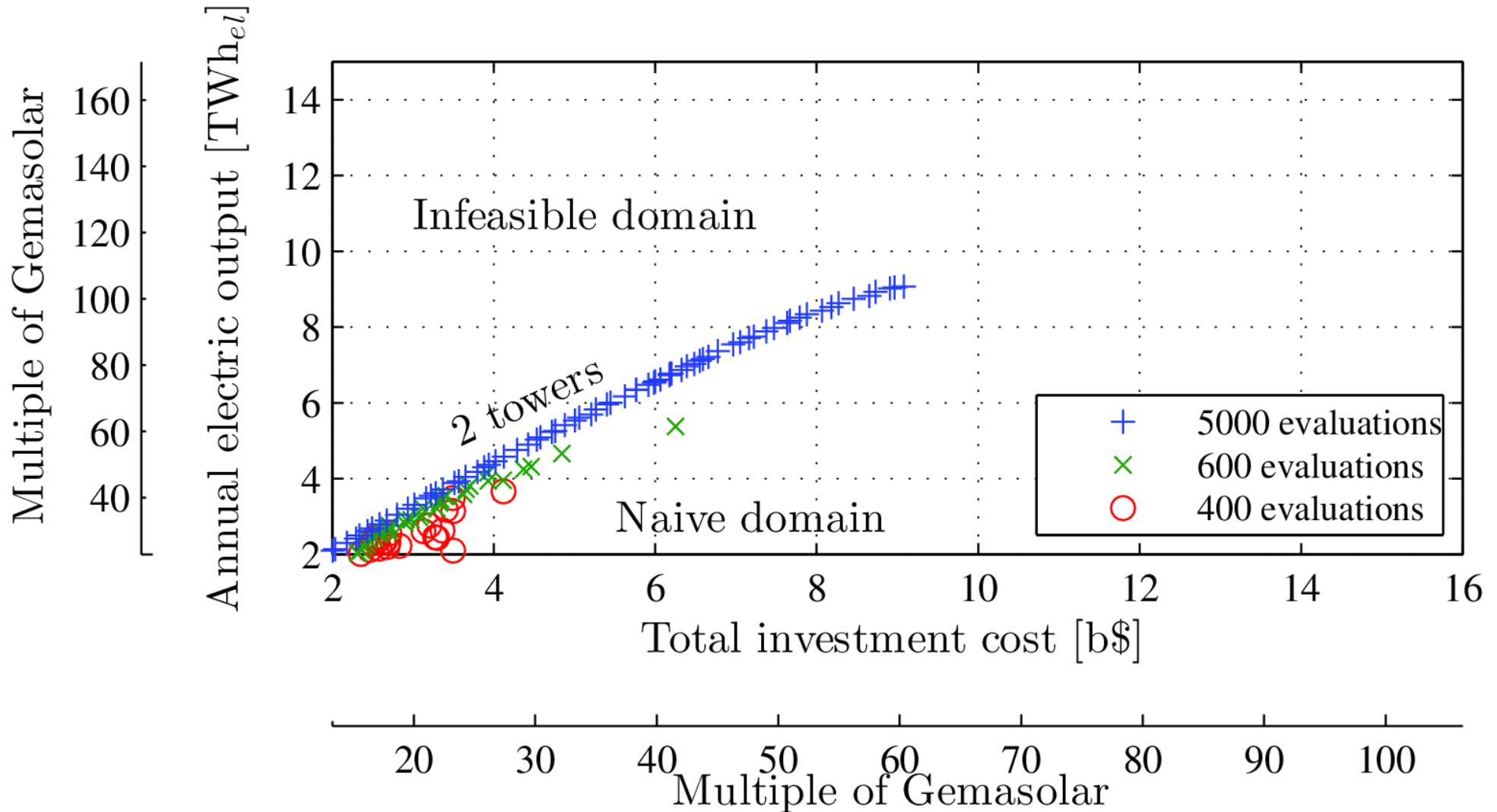


# 7. Optimum transition

## 7.2. From 2 to 3 towers



# 6. Thermo-economic optimisation



# 6. Thermo-economic optimisation

