15th Conference on Energy Economics and Technology (ENERDAY)
April 9, 2021

The potential of sufficiency measures to achieve a fully renewable energy system – a case study for Germany

Citlali Rodriguez del Angel*, Dylan Manning*,
cra@wip.tu-berlin.de, dylan.manning@campus.tu-berlin.de,

Alfredo Zamora Blaumann, Michel Kevin Caibigan, Mirjam Helena Eerma, Seyedsaeed Hosseinioun, Carl-Christian Klötzsch, Morteza Lavaiyan, Gro Lill Økland, Eric Rockstädt, Paul Seifert, Nithish Kini Ullal, Johanna Winkler, Elmar Zozmann

Motivation

- **Climate change is an existential threat, but even countries with commitments are not doing enough to meet 1.5 degrees**

- **Most studies focus on supply side solutions**

- **Demand side studies focus primarily on efficiency, leaving need for quantitative sufficiency studies**

- **Goal of paper is to demonstrate, through a least-cost expansion model and extensive literature review, the significant cost savings associated with sufficiency measures. This can help direct future studies, as well as influence government policy**

Introduction

Sufficiency as a theoretical framework

- Several definitions for “energy sufficiency” in related literature
- *“Sufficiency as the reduction of energy consumption to a level where benefit is not significantly diminished”*
- Demand side reductions by behavioral change

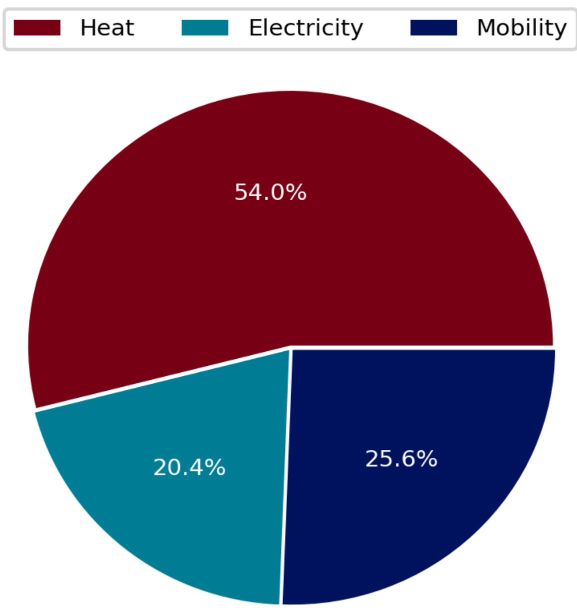
→ What is the potential of sufficiency-based demand reductions and what impacts do they have on the supply side of a 100% renewable energy system in Germany?

Introduction

Relevant literature for sufficiency and energy system modeling

- Fraunhofer (2020); Paths to a Climate-neutral Energy System
- negaWatt Assosiation (2018); Energy sufficiency - Towards a more sustainable and fair society
- Umweltbundesamt (2015); Konzept zur absoluten Verminderung des Energiebedarfs
- Ven et al. (2018); The potential of behavioural change for climate change mitigation: A case study for the European Union
- Data: openENTRANCE project, scenario “social commitment” compliant with the Paris Agreement

Reference Case



Total annual demand: 1465.21 TWh

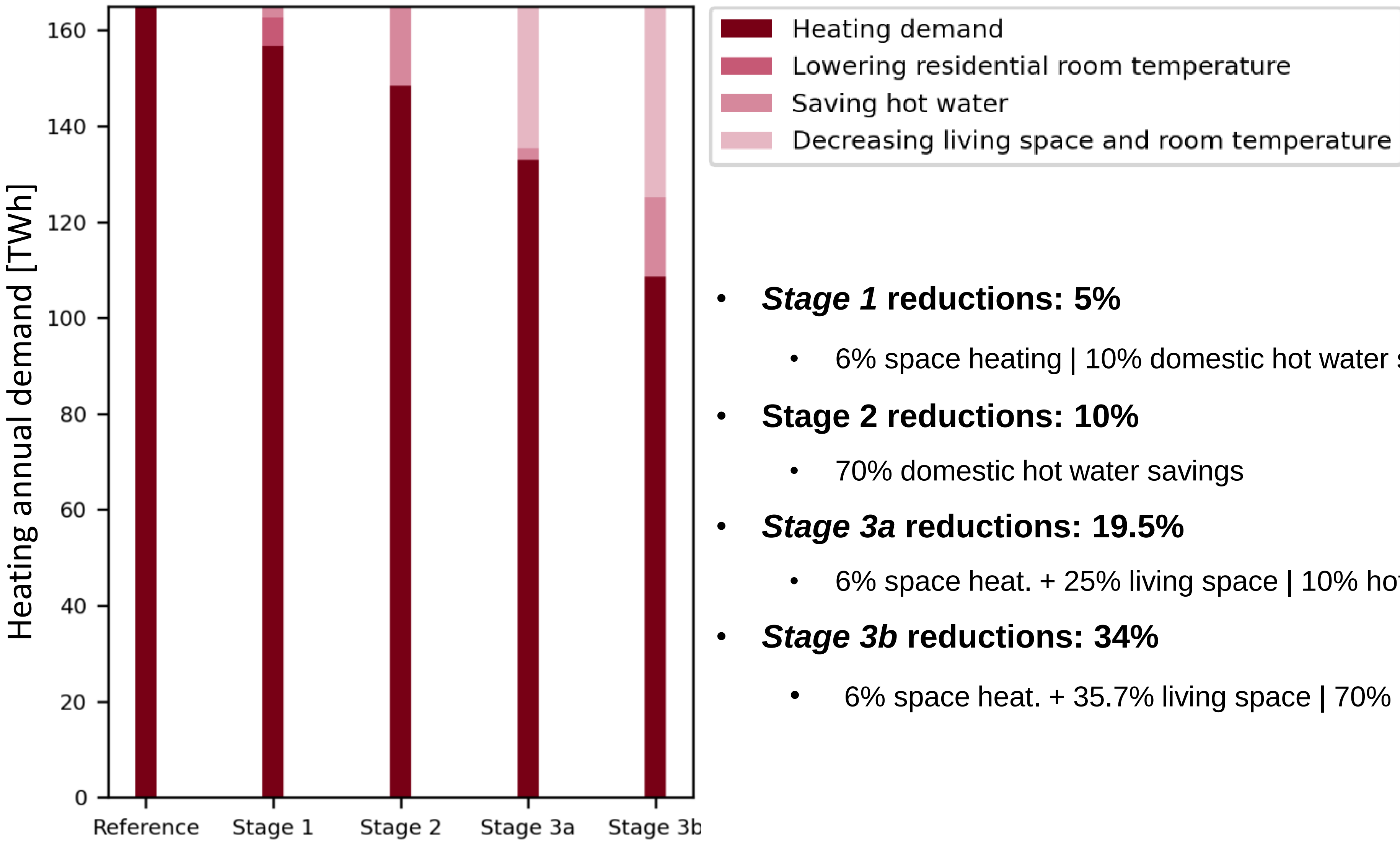
Sectors	Included subsectors	Energy carriers
Heat	• Residential and Industrial heat demand • Space heating, hot water, low/mid/high process heat	• Hydrogen • Synthetic gas • Electricity
Mobility	• Passenger / Freight • Road • Rail • Air	• Hydrogen • Electricity
Conventional Electricity	• Residential/Commercial/ Industrial • Lighting, communication technology, space cooling, domestic appliances (frigde, TV, …)	• Electricity • Hydrogen as long term storage

Quantifying the potential for demand reductions – A literature overview

Quantifying the potential for demand reductions: Residential/Commercial Space Heating, Hot Water, Industrial Heat

Measure	Value range	Source
Space heating demand		
Lowering average room temperature by 1-2°C	-4.4% to -9%	(Umweltbundesamt, 2015; Marshall et al., 2016)
Turning down thermostat by 1°C	-13%	(Palmer et al., 2012)
Decreasing living space per person	-24.9% to 35.7%	(Bierwirth and Thomas, 2019b)
Hot water consumption		
Water efficient shower heads	-50%	(Palmer et al., 2012)
Feedback system about showering time	-5% to -10%	(Toulouse and Attali, 2018)
Shorter and less frequent showering	-20% to -30%	(Palmer et al., 2012)
Adjusting water consumption	-70%	(Lehmann et al., 2015)
Process heat low temperature		
Decreasing food waste	8.6% - 13.2%	(Schmidt et al., 2019; Vita et al., 2019)
Process heat mid temperature		
Increasing plastic recycling	1.4% - 2.1%	(Umweltbundesamt, 2021; Chemischen Industrie, 2020; Association négaWatt, 2018)
Extending useful life of products and	3% - 8.2%	(Prakash et al., 2016)
establishing service-based sharing economy	-	(Vita et al., 2019)
Modal shift construction products and	0.67% - 1.03%	(Hertwich et al., 2019; Bundesverband Baustoffe – Steine und Erden, 2019)
reduced construction materials	-	
Process heat high temperature		
Modal shift construction products and	3% - 7.6%	(Hertwich et al., 2019; WV-Stahl, 2020)
reduced construction materials	-	

Potential for demand reductions: Residential/Commercial Space Heating and Hot Water

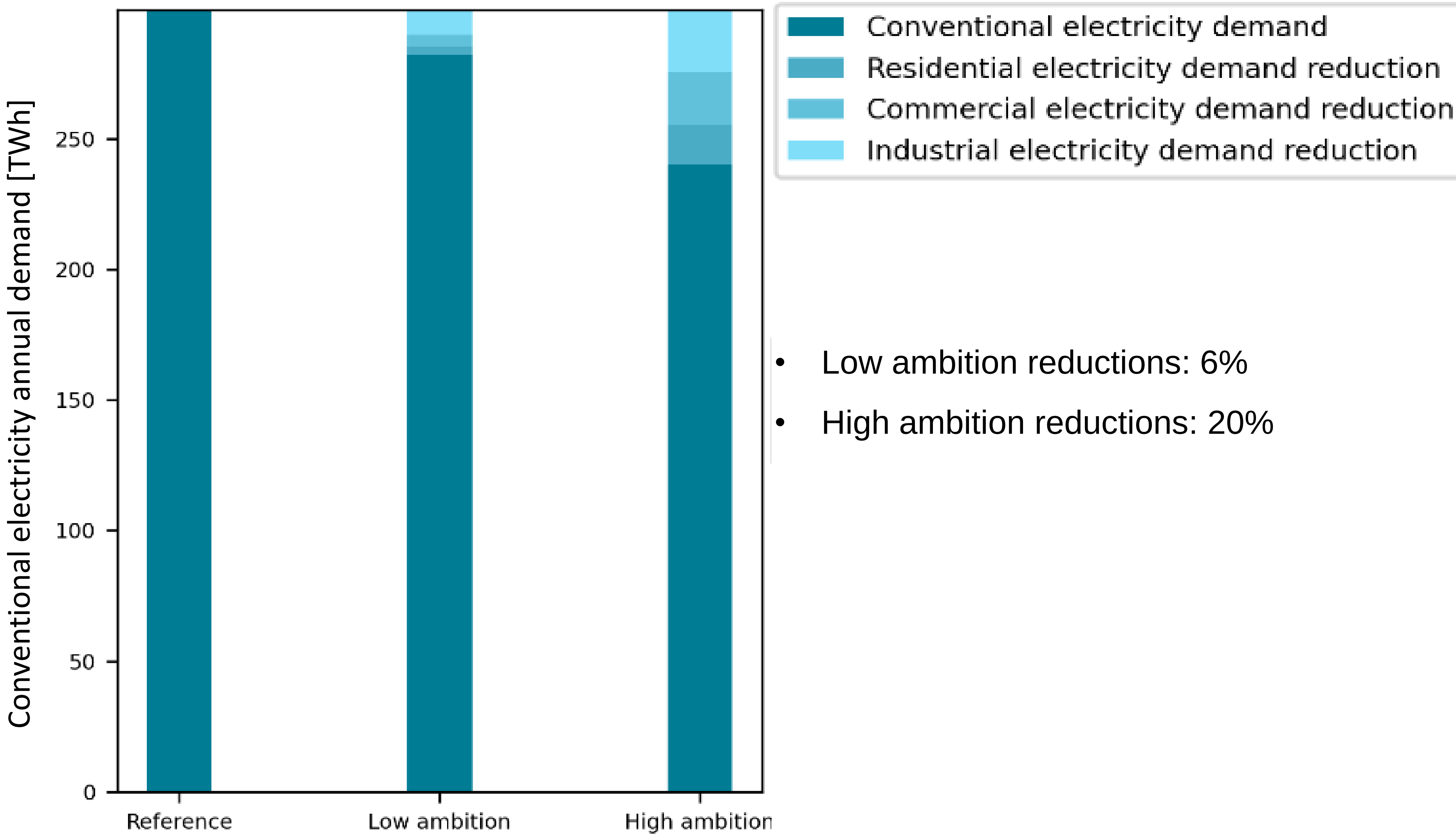


- ***Stage 1* reductions: 5%**
  - 6% space heating | 10% domestic hot water savings
- **Stage 2 reductions: 10%**
  - 70% domestic hot water savings
- ***Stage 3a* reductions: 19.5%**
  - 6% space heat. + 25% living space | 10% hot water
- ***Stage 3b* reductions: 34%**
  - 6% space heat. + 35.7% living space | 70% hot water

Quantifying the potential for demand reductions: Conventional Electricity Sector

	Instruments	Measures	Reduction	Source
Residential	Behavioral change through intervention	Direct Feedback	5-15%	Martiskainen (2007)
		Direct feedback applications (Europe and N.America)	9%	Zangheri et al. (2019)
		Indirect feedback applications (Europe and N.America)	4%	Zangheri et al. (2019)
		Goal setting	4.50%	Martiskainen (2007)
		Goal Setting with feedback	15.10%	Martiskainen (2007)
		Feedback through smart meters and time-use tariffs (Ireland)	1.80%	Carroll et al. (2014)
		Feedback (peak reduction)	7.80%	Carroll et al. (2014)
		Change of human behavior	20%	Bürger (2009)
	Change in user behavior through intrinsic motivation	Sufficiency in lighting and appliances	15-20%	Umweltbundesamt (2015)
		Change of human behavior	20%	Bürger (2009)
Commercial	Behavioral change through intervention	Group level feedback	7%	Carrico and Riemer (2011)
		Goal setting	12.90%	Nilsson et al. (2015)
		Goal setting with feedback etc.	5.5 and 6%	Nilsson et al. (2015)
	Behavioral change through use of technology	Energy information system + social marketing - feedback (Community Based Social Marketing)	12%	Owen et al. (2010)
	Revolutionary changes through legislations	Four-day week/shorter working time/less production	10.50%	Hansen et al. (2009)
Industrial	Behavioral change through intervention	Energy Audits (Denmark)	7 - 20%	Larsen et al. (2006)
		Energy information system + social marketing - feedback (Community Based Social Marketing)	12%	Owen et al. (2010)
	Revolutionary changes through legislations	Four-day week/ shorter working time/ less production	10.50%	Hansen et al. (2009)

Potential for demand reductions: Conventional Electricity Sector

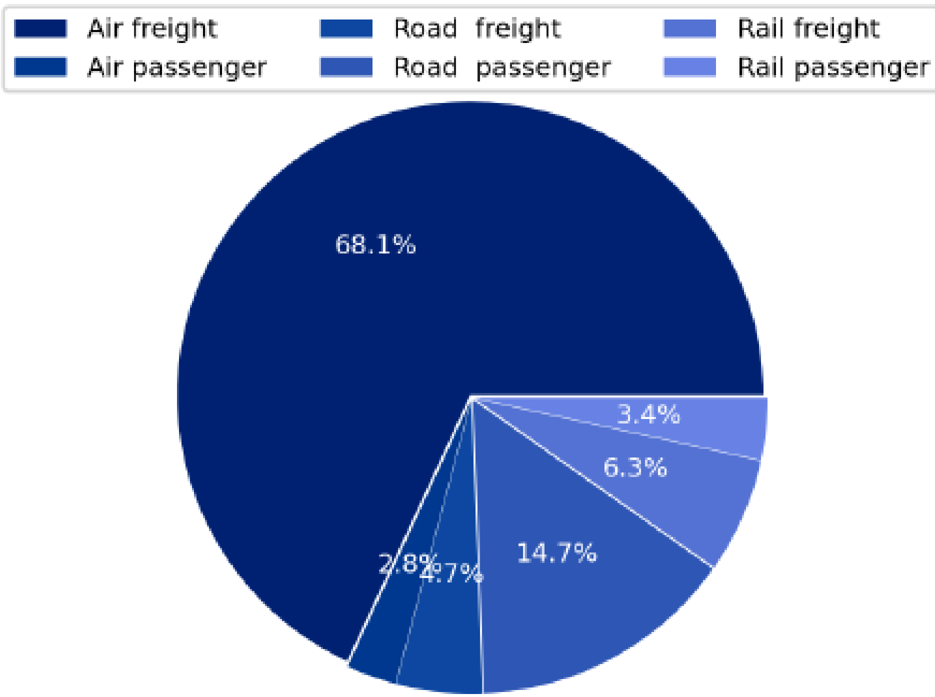


- Low ambition reductions: 6%
- High ambition reductions: 20%

Quantifying the potential for demand reductions: Mobility Sector

Measure	Value range	Source
Bicycles		
Modal shift from to cycling	-3.5 to -10%	(Umweltbundesamt, 2015; van de Ven et al., 2018)
Increased level of investment in bike infrastructure	+50 to +100%	(Venturini et al., 2019b)
Increased share of E-Bikes in total	+1 to +50%	(Venturini et al., 2019b)
Motorized individual transport		
Replacing business trips with telemeetings	-40% to -60%	(Umweltbundesamt, 2015)
Smaller passenger cars through regulation	-7.5%	(Umweltbundesamt, 2015)
Reduction of motorized individual transportation	-30%	(Sterchele et al., 2020)
Reduced commuting demand through teleworking	-1% to -20%	(van de Ven et al., 2018; Venturini et al., 2019b)
Increased load factor for every commute car trip (carpooling)	load factor 2	(van de Ven et al., 2018; Venturini et al., 2019b)
Public transport		
Modal shift to public transport for all commuting demand	-100%	(van de Ven et al., 2018)
Reduced traveling time of public transport	-1% to -10%	(Venturini et al., 2019b)
Aviation		
Reduction of aviation	-55%	(Sterchele et al., 2020)
Reduction of private aviation	-50%	(Umweltbundesamt, 2015)
Avoid flights that can be replaced by another transport mode <10h	-25%	(van de Ven et al., 2018)
Replace intercontinental leisure flights with intra-EU trips	-50%	(van de Ven et al., 2018)

Quantifying the potential for demand reductions per sector: own calculations on the example of Mobility



Calculated Sufficiency Measurements in Mobility

Road Freight:

- Space optimization (Roth et al., 2015)
  - Avoid empty trips
  - Under-utilization of available capacity
- Less online shopping returns (Goebel)

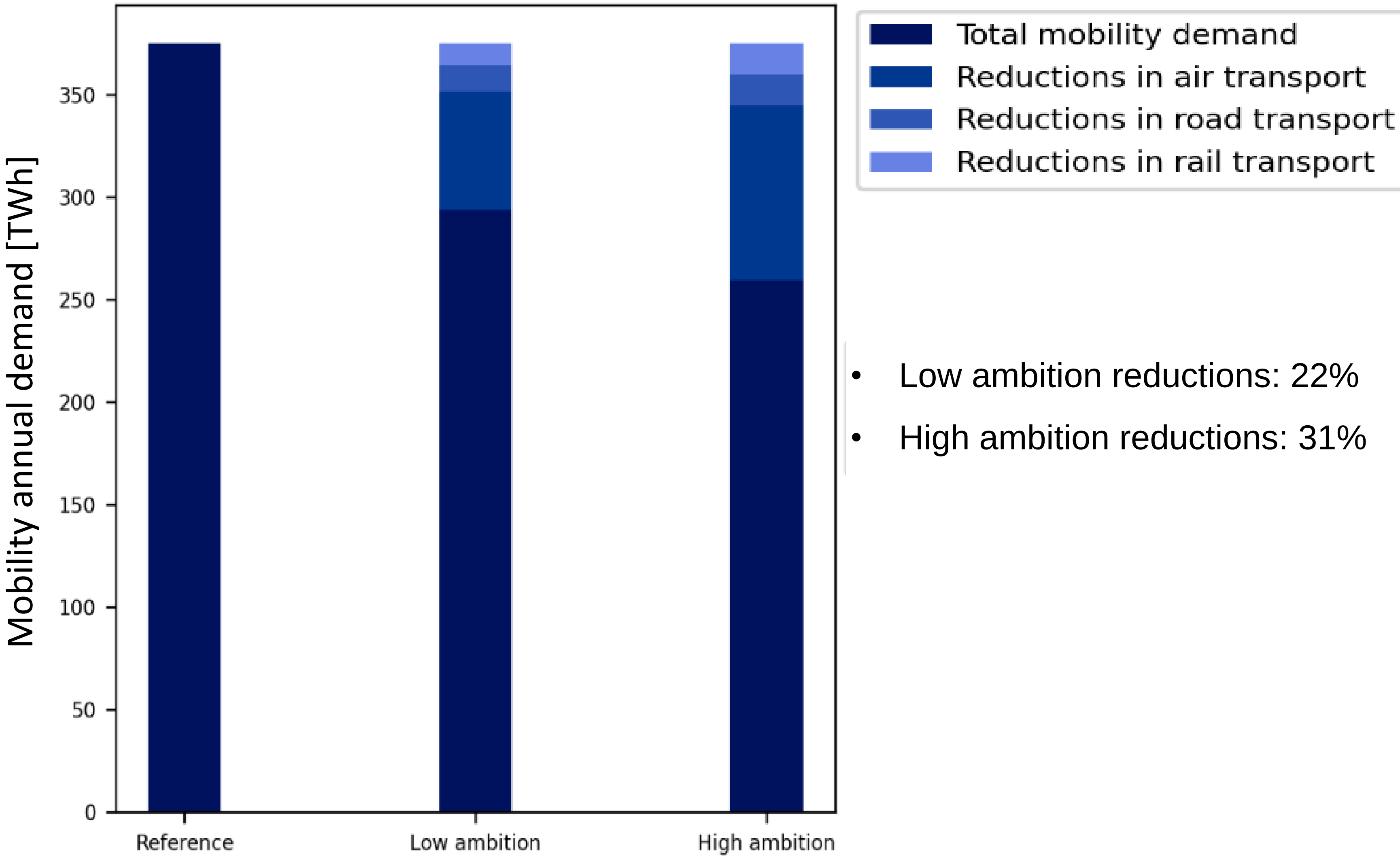
→ Reduction potential of 29% - 44%

Air freight:

- 22% air cargo intra-continental (EUROSTAT 2019)
  - replace by trains / ships

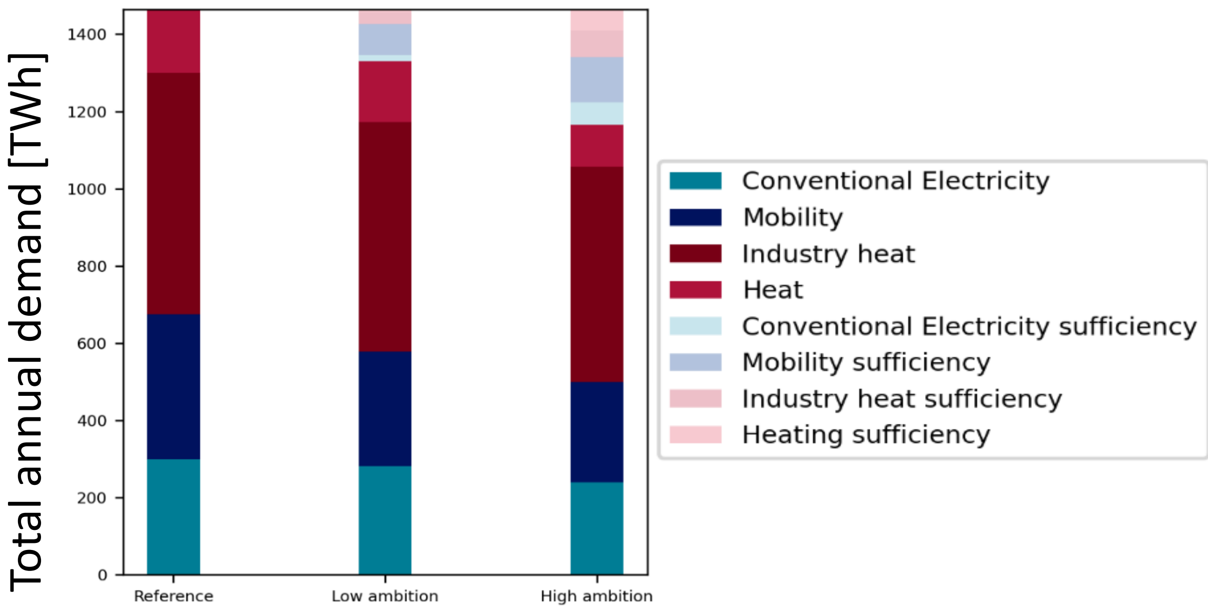
→ Reduction potential of 20% - 30%

Potential for demand reductions: Mobility Sector



- Low ambition reductions: 22%
- High ambition reductions: 31%

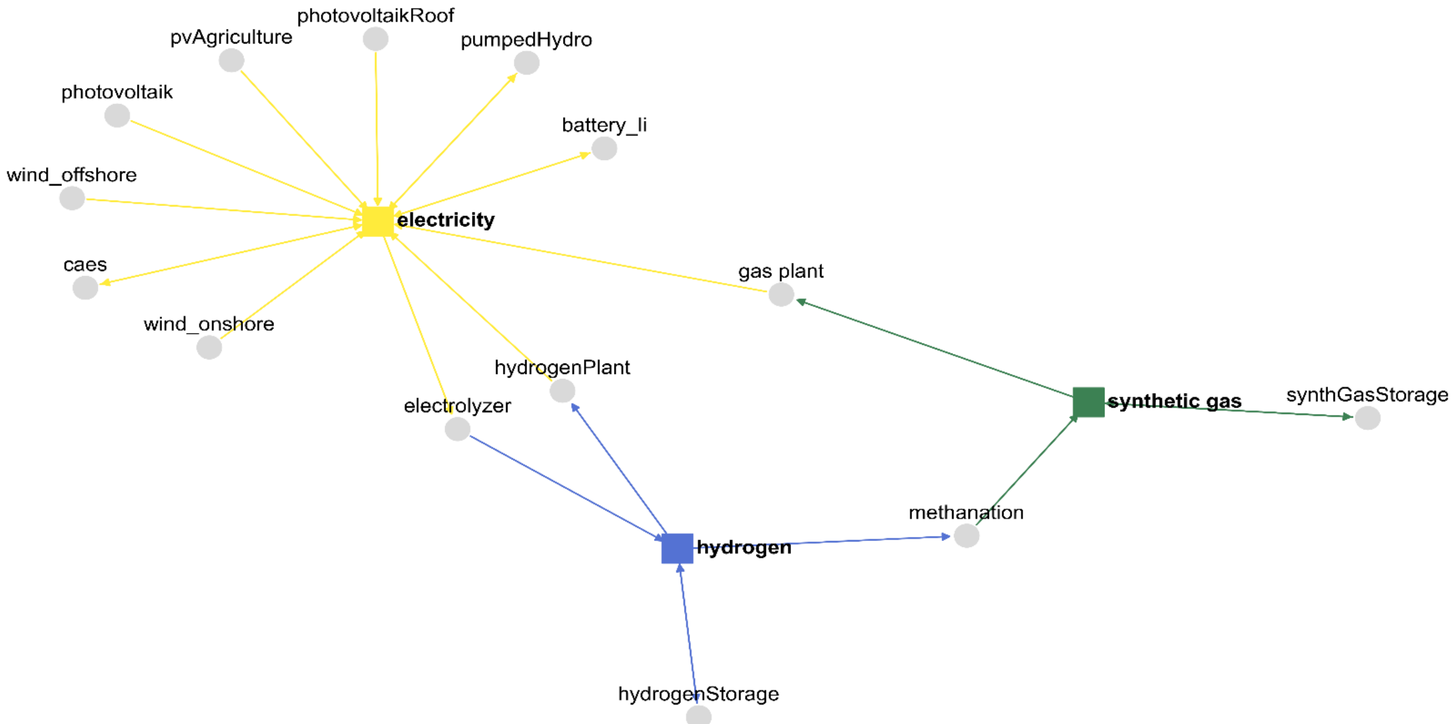
Combined Scenario



Sector combined reductions	Reference	Low ambition	High ambition
Total demand reductions	0%	**9.4%**	**20.5%**

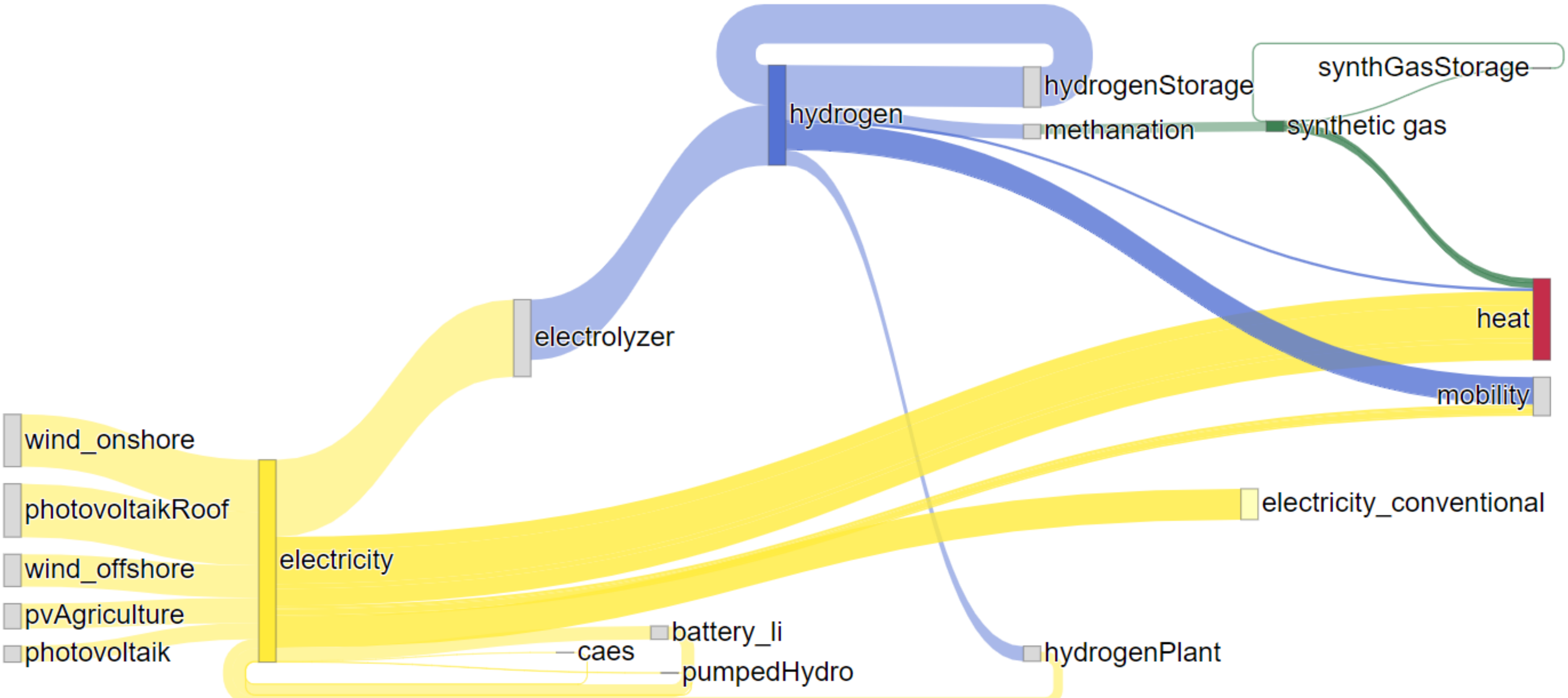
Modeling approach

- AnyMOD is a graph-based framework that facilitates modeling high levels of renewable resources and sector integration (Göke, 2020a)
- Renewable capacities derived from openENTRANCE
- Demand data from openENTRANCE
- Cost assumptions for technologies from Kost et al.(2018), Trommsdorff (2020), and Göke et al. (2019)

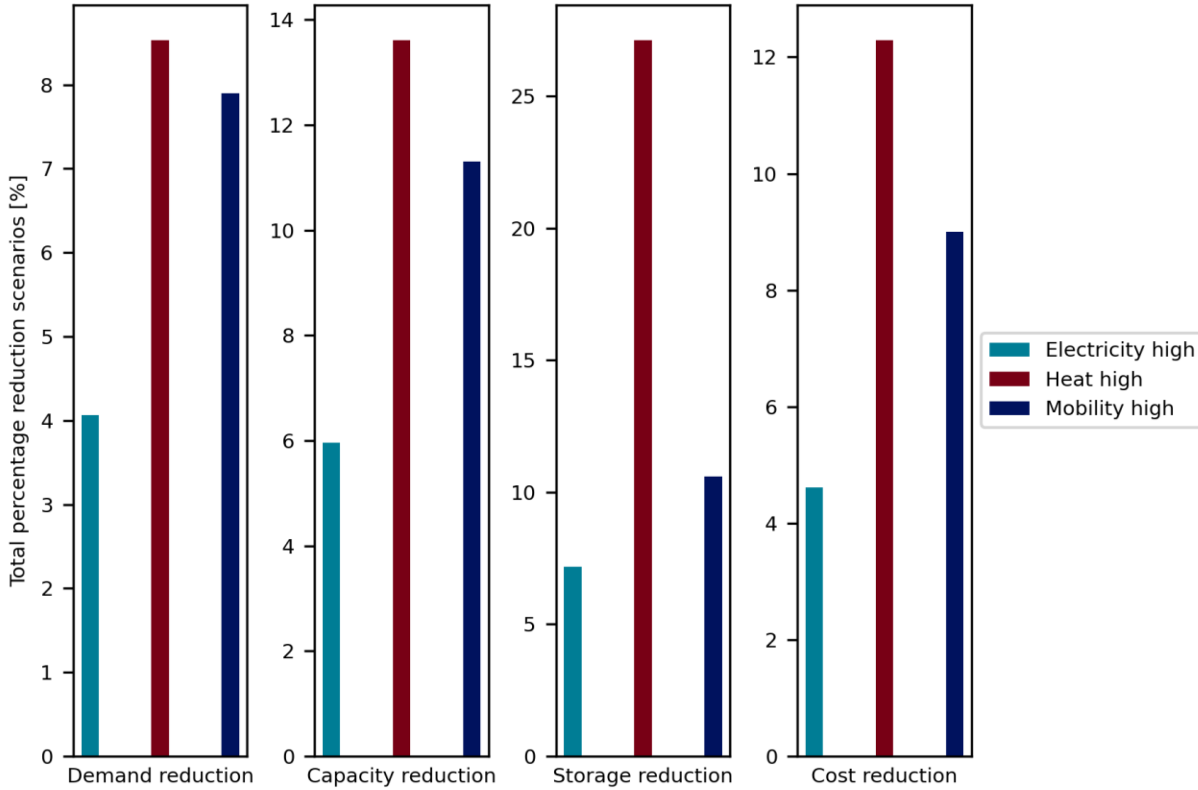


Modeling approach

- No imports/exports
- 100% of energy from sources within Germany
- Split into three sectors, heat, mobility, and conventional electricity

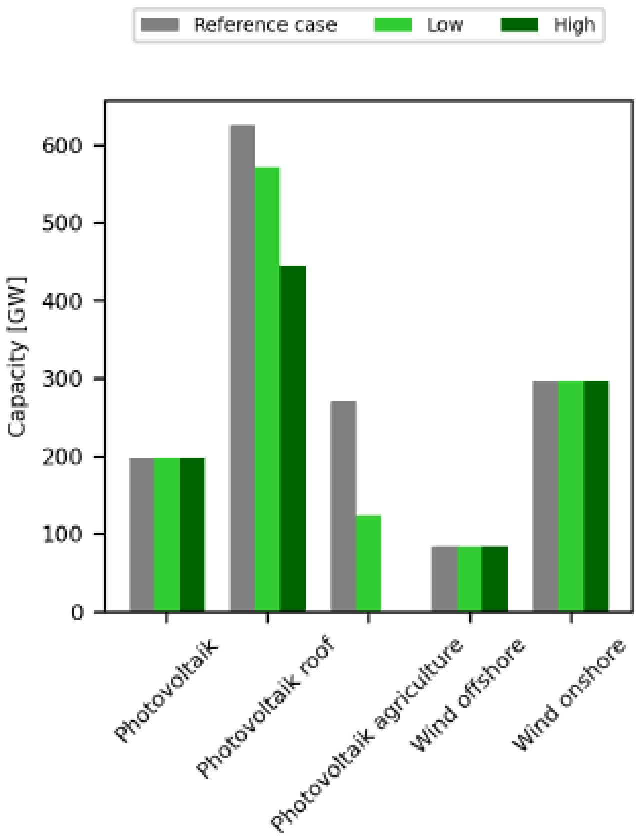


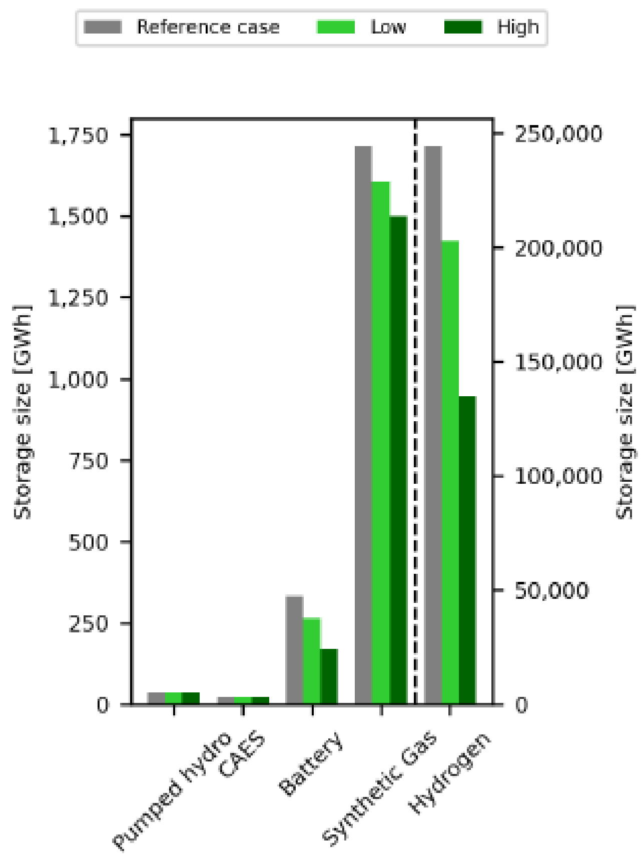
Results – Sectoral Scenarios



- Sectoral scenarios show similar results
- Demand reductions are roughly proportional to cost, capacity, and storage savings
- Exception is heat, which has outsized reduction in storage. Characteristic of high peak loads

Results – Combined Scenarios

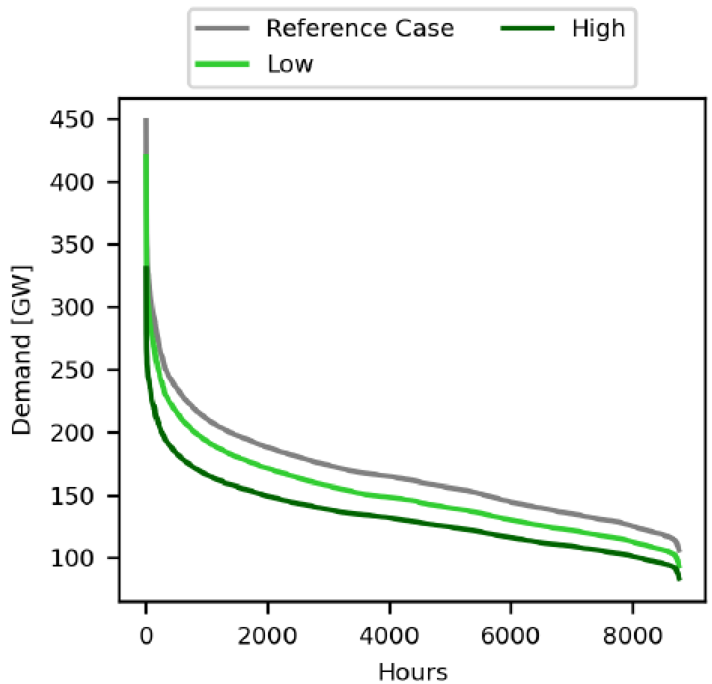


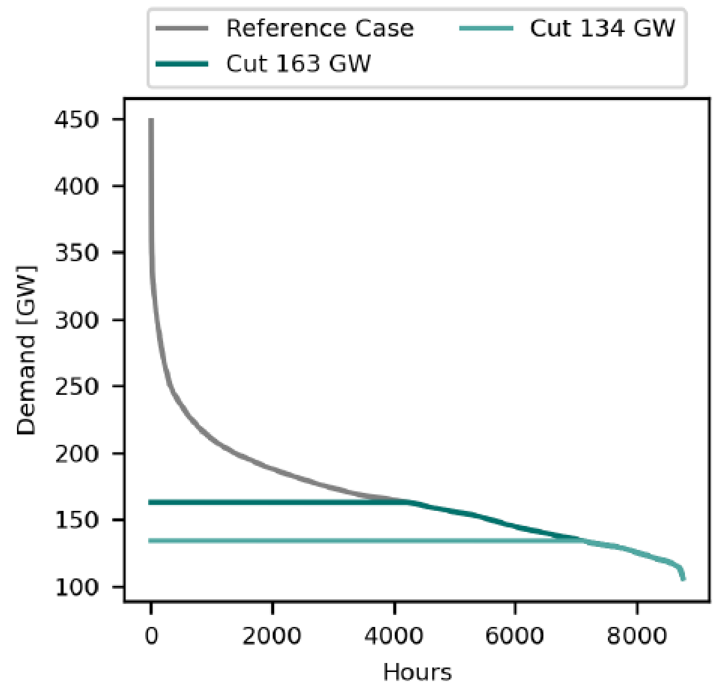


- Reductions begin in agricultural PV, then continue in rooftop PV
- Hydrogen is on much larger scale than other storage technologies
- Reductions lead to significant cost savings
- As renewable capacity expansion continues, political/social resistance will become an issue, as the model maxes potential capacity for wind/open-space solar. Reductions are crucial to overcoming this resistance

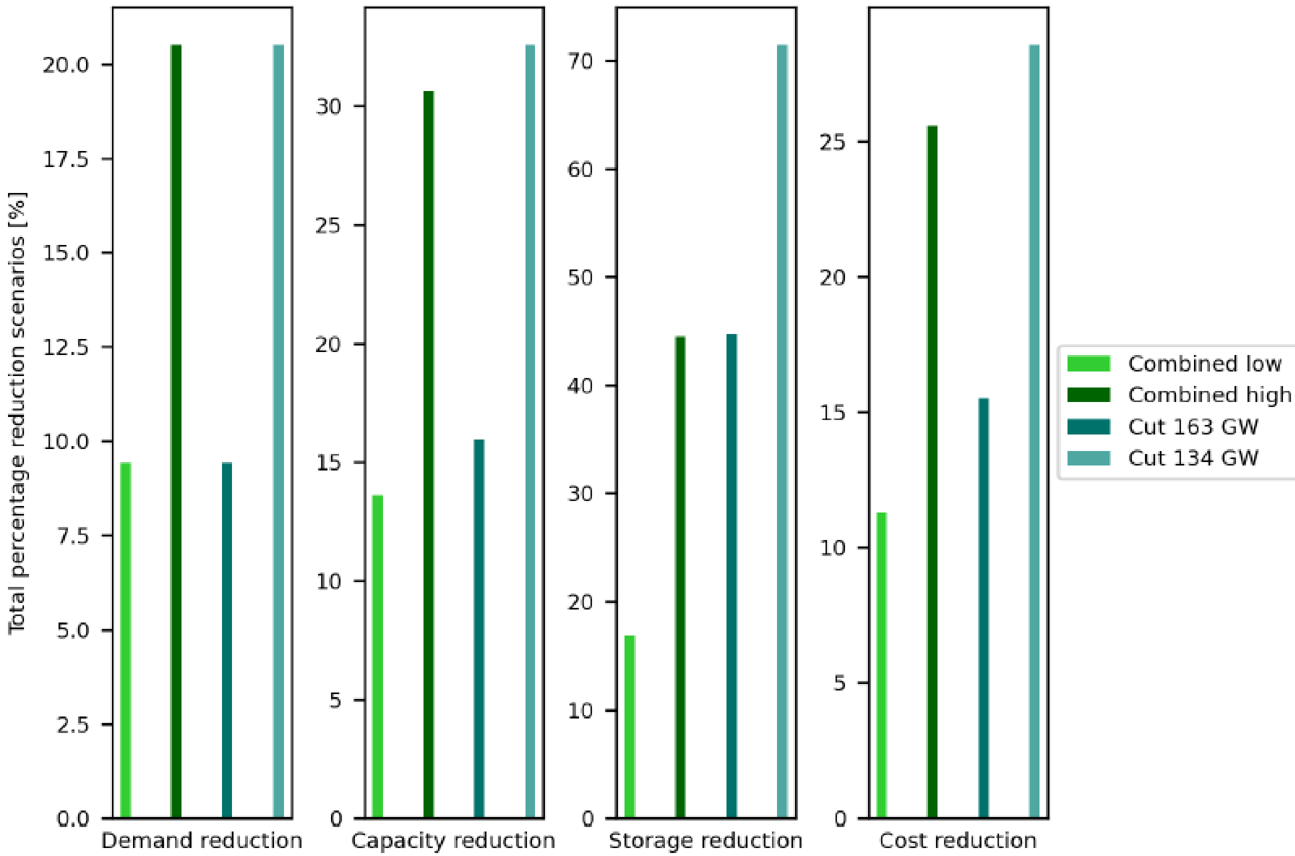
Scenarios

Reference Scenario	Sectoral Scenarios	Combined Scenarios	Sensitivity Analysis
▪ Reference case ▪ Unchanged demand from openENTRANCE	▪ Sectoral demand reduction for heat, mobility and conventional electricity	▪ All sectors combined ▪ Low and high ambition scenarios	▪ Peak load shedding





Results – Peak Load Shedding



- Combined low and high have the same demand reductions as Cut 163 and 134, respectively
- Large storage reduction
- Demand reduction is important, but made much more valuable by focusing on periods of peak demand
- Strengthens argument for load shedding and shifting, whether that be through sufficiency measures or otherwise

Conclusion

- **Demand reductions through sufficiency measures can significantly reduce the cost of producing 100% of the energy**

- **By reducing capacity expansion required, risk of running into social acceptance barriers for expansion is also reduced**

- **Further studies are warranted in order to influence policy moving forward**

References

Göke, L., Poli, D., and Weibezahn, J. (2019).Current and Perspective Technology and CostData of Flexibility Options. Tech. rep. OSMOSE Project EU Horizon 2020.

Kost, C., Shammugam, S., Jülch, V., Nguyen, H.-T., and Schlegl, T. (2018).Stromgeste-hungskosten Erneuerbare Energien. European Union Horizon 2020 Research Paper. Freiburg, Ger-many: Fraunhofer Institute.

Trommsdorff, M. (2020).Agri-Photovoltaik: Chance Für Landwirtschaft und Energiewende. Fraun-hofer Research Paper. Freiburg, Germany: Fraunhofer ISE.

Thank You!