Technological, Economic and Market Prospects of All-Electric Aircraft

Decarbonizing Air Transport
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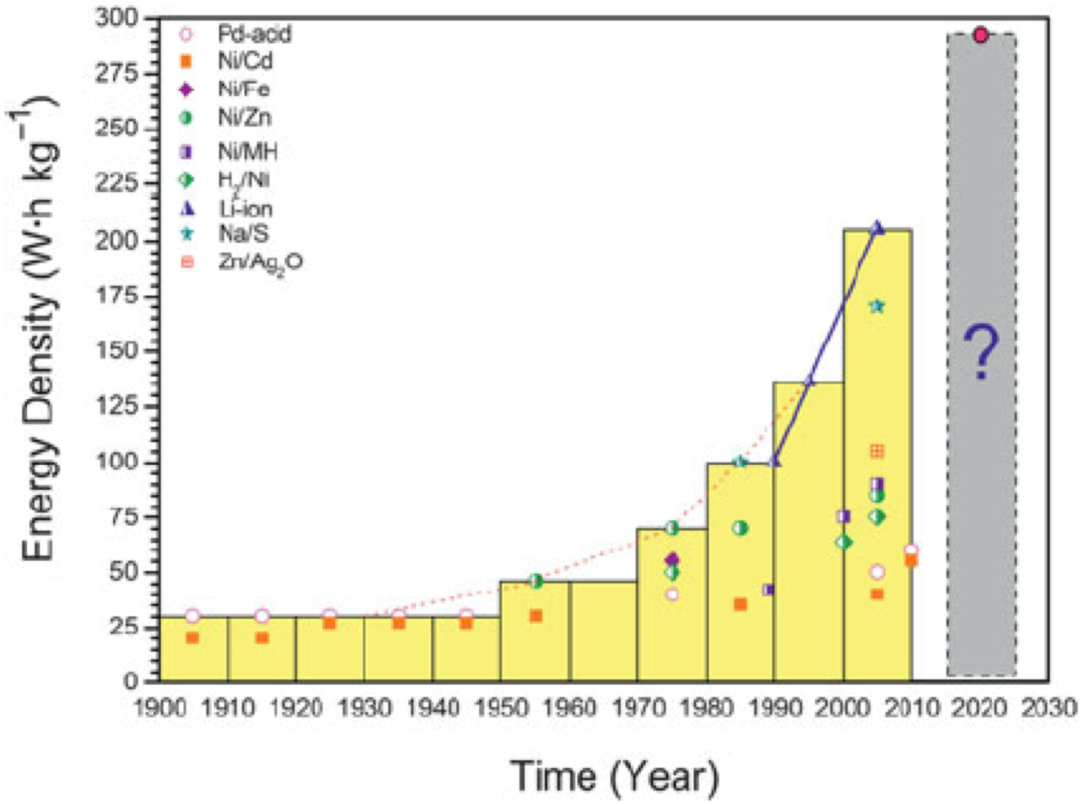
Battery Specific Energy has increased by ~ 3%/yr

(A doubling every 20-25 years)



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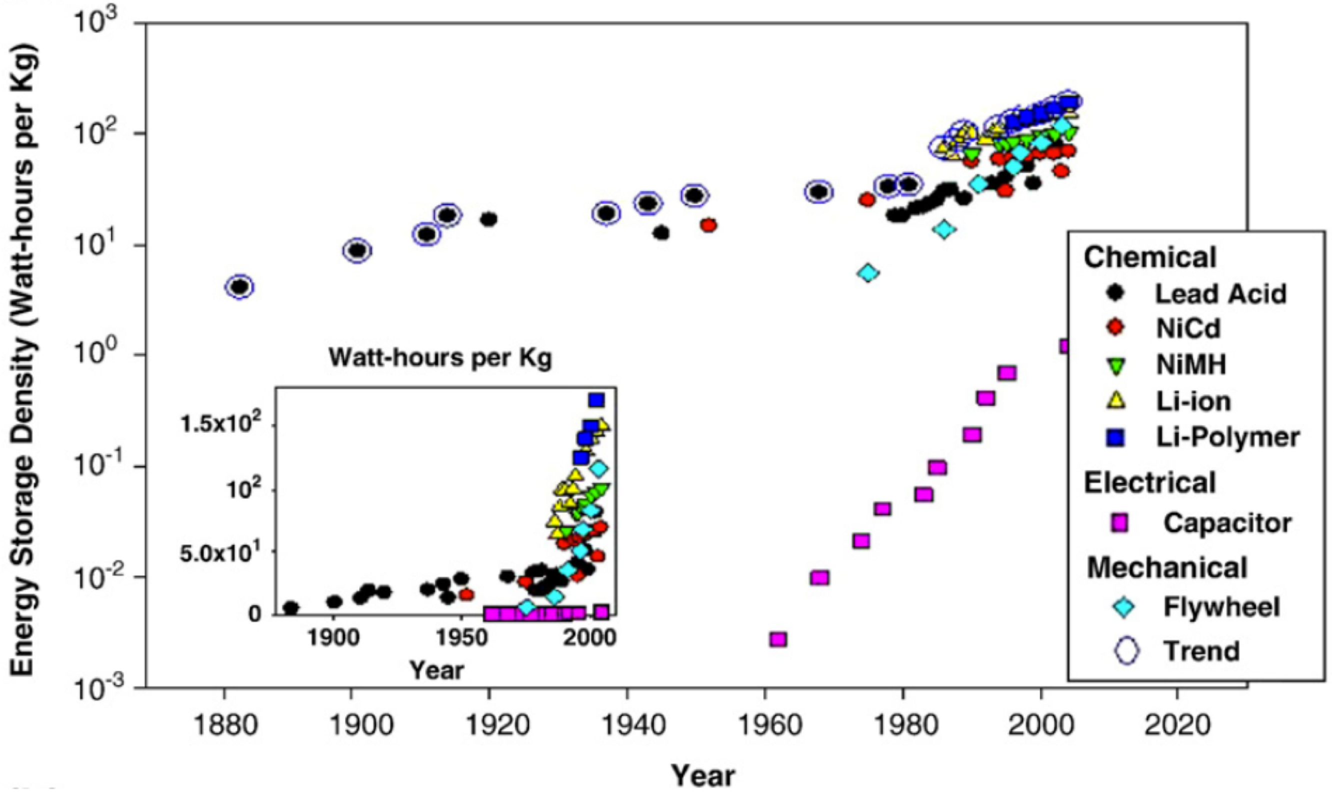

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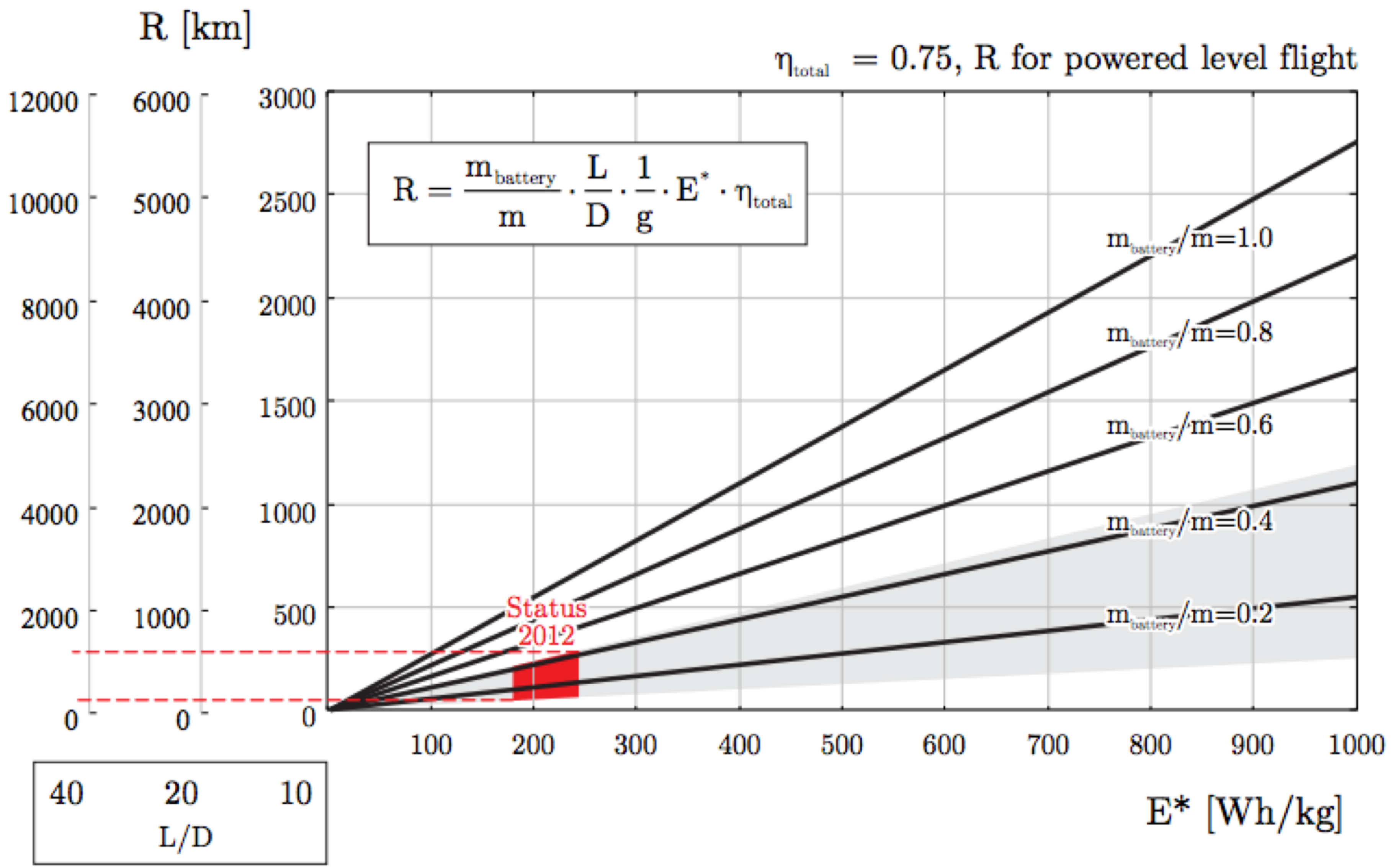
(Breguet) Range Equation: All-Electric Aircraft



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Technical and environmental assessment of all-electric 180-passenger commercial aircraft

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A B S T R A C T

Aviation emissions contribute adversely to climate change and air pollution due to combustion emissions. While biofuels can reduce the lifecycle CO_2 emissions and combustion soot emissions, and hybrid- or turbo-electric aircraft may result in reduced fuel burn and overall emissions, only all-electric aircraft offer a potential opportunity for zero in-flight emissions in the long term. Over the past decade, more than 70 all-electric conceptual, experimental, and commercial aircraft have been researched, with a particular focus on light aircraft. These designs are reviewed, along with progress in battery technology. An all-electric aircraft design and optimization program, TASOPTe, has been developed from an existing version for conventionally-powered aircraft, TASOPT. Both programs are largely based on first-principles, enabling the design of aircraft with unusually short design ranges. A series of optimized 180-passenger aircraft based on the Airbus A320neo configuration are designed and evaluated at 200–1600 nmi design ranges with 2–10 propulsors and 400–2000 Wh/kg batteries. The performance of these all-electric aircraft is compared to advanced conventionally-powered aircraft optimized for the same design ranges. Optimized all-electric aircraft are found to use two or four

nature energy

ANALYSIS

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Technological, economic and environmental prospects of all-electric aircraft

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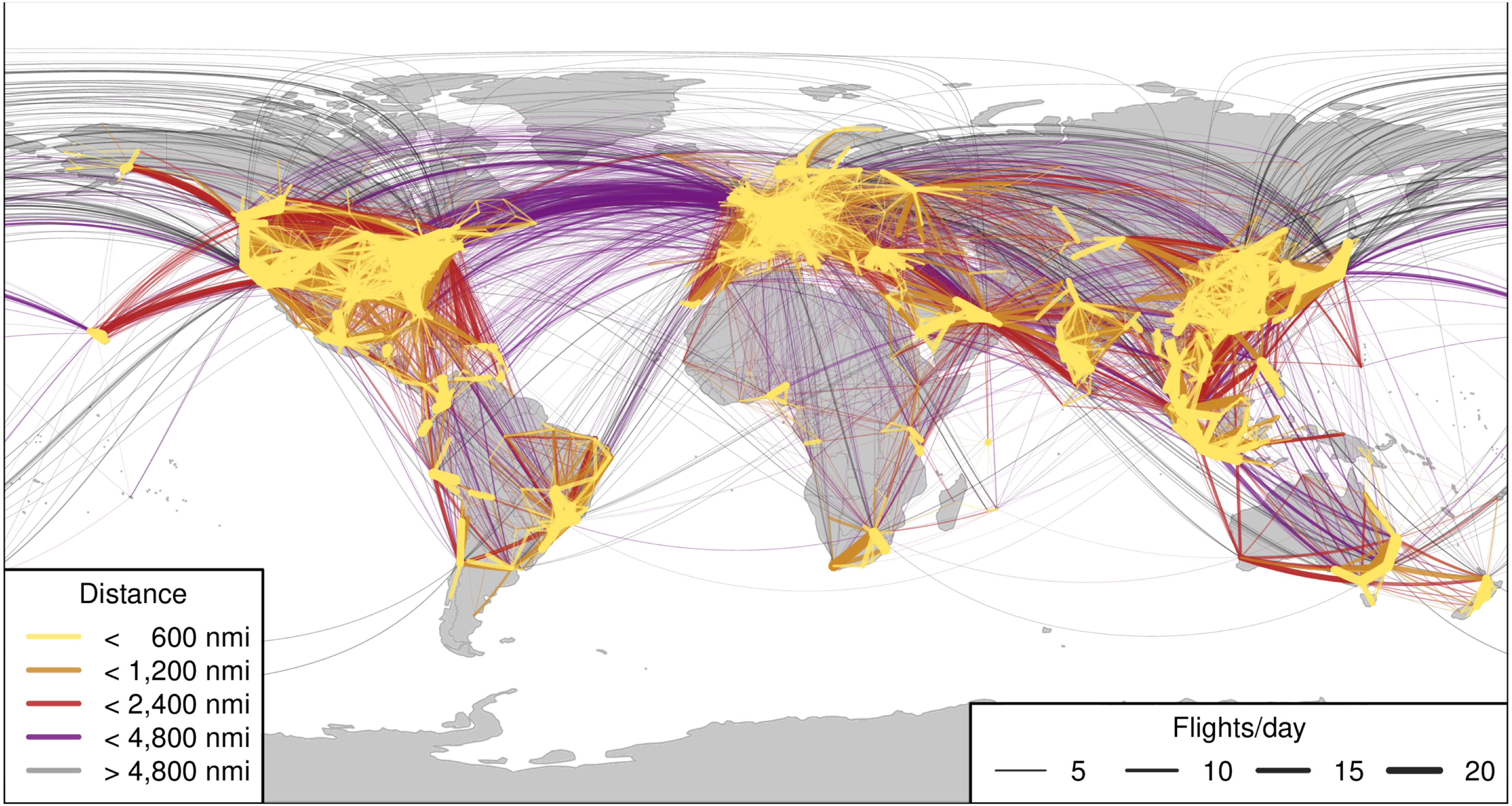
Ever since the Wright brothers' first powered flight in 1903, commercial aircraft have relied on liquid hydrocarbon fuels. However, the need for greenhouse gas emission reductions along with recent progress in battery technology for automobiles has generated strong interest in electric propulsion in aviation. This Analysis provides a first-order assessment of the energy, economic and environmental implications of all-electric aircraft. We show that batteries with significantly higher specific energy and lower cost, coupled with further reductions of costs and CO_2 intensity of electricity, are necessary for exploiting the full range of economic and environmental benefits provided by all-electric aircraft. A global fleet of all-electric aircraft serving all flights up to a distance of 400–600 nautical miles (741–1,111 km) would demand an equivalent of 0.6–1.7% of worldwide electricity consumption in 2015. Although lifecycle CO_2 emissions of all-electric aircraft depend on the power generation mix, all direct combustion emissions and thus direct air pollutants and direct non-CO_2 warming impacts would be eliminated.

All-Electric Aircraft Market Size by Distance



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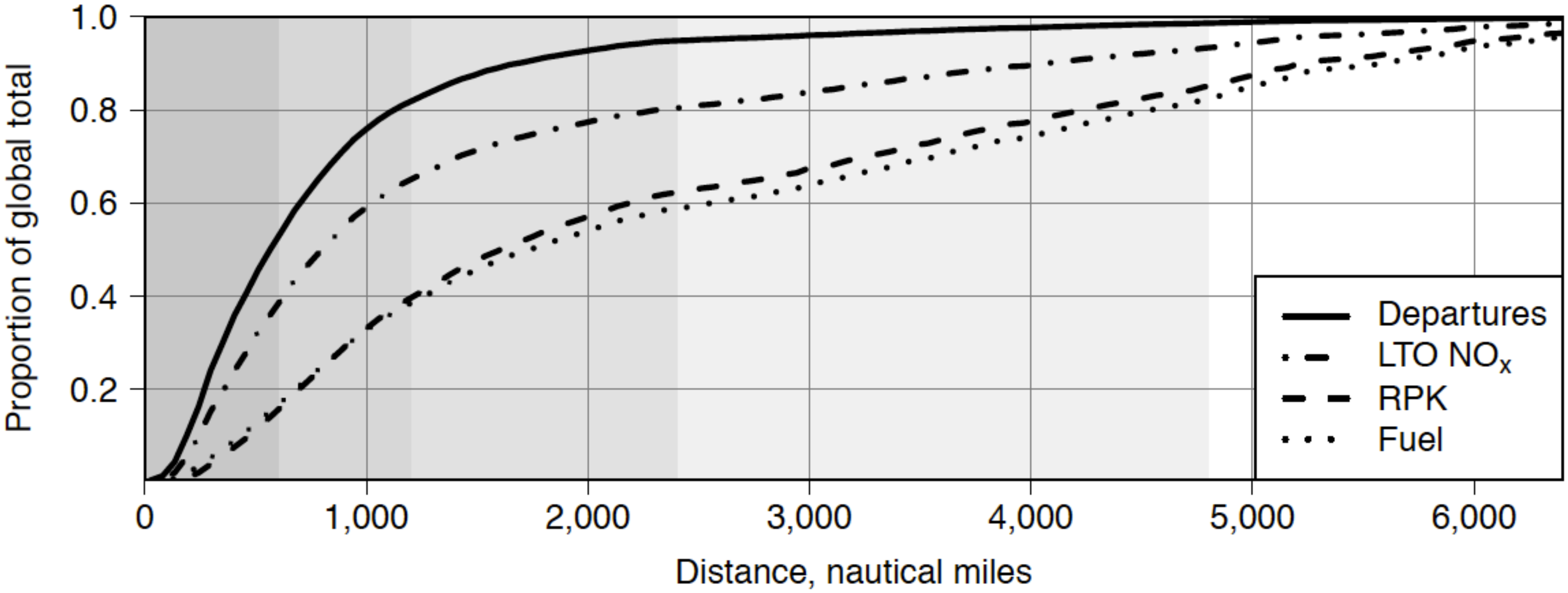
Key Air Transportation Characteristics



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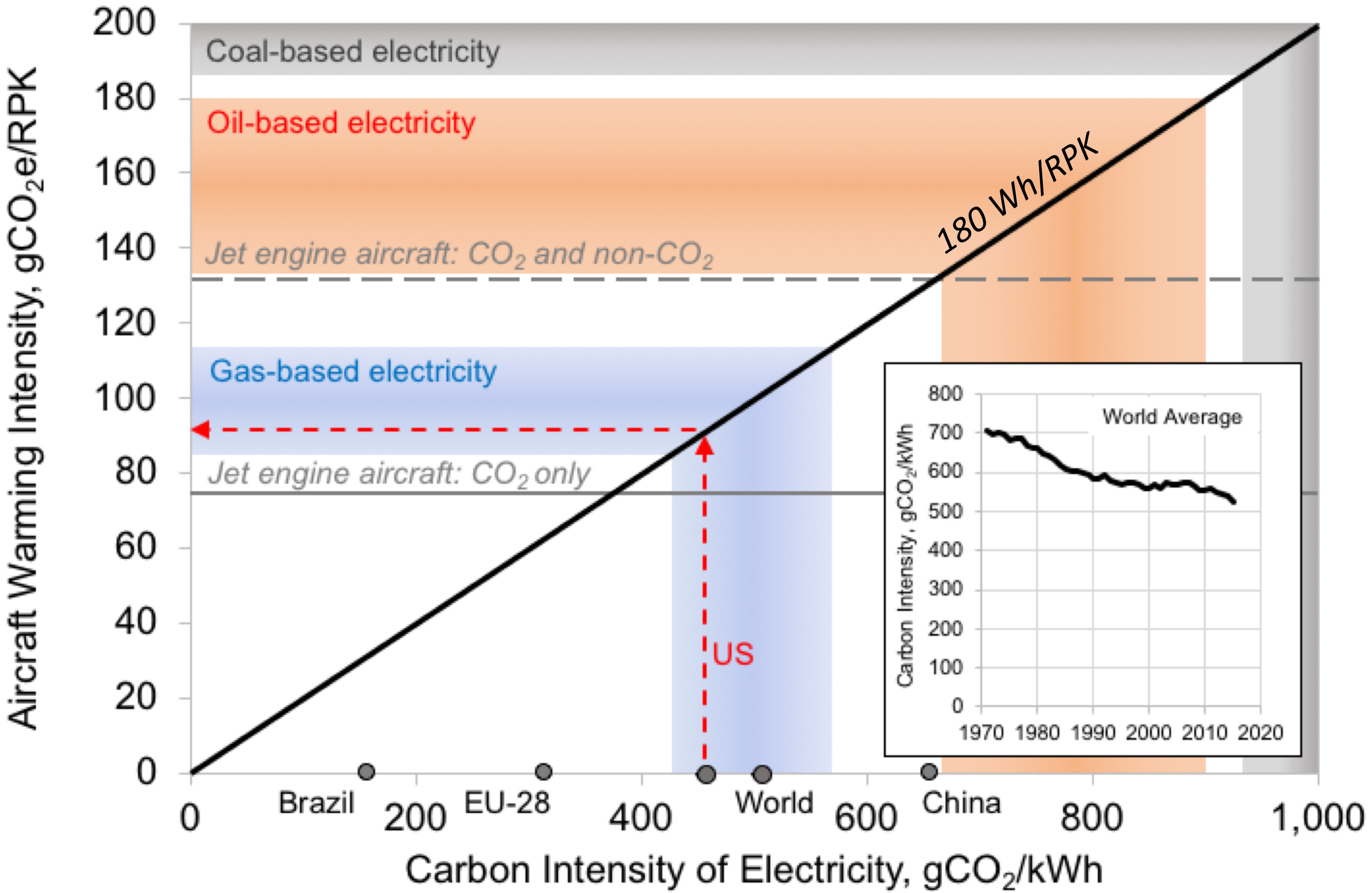
Aircraft Warming Intensity



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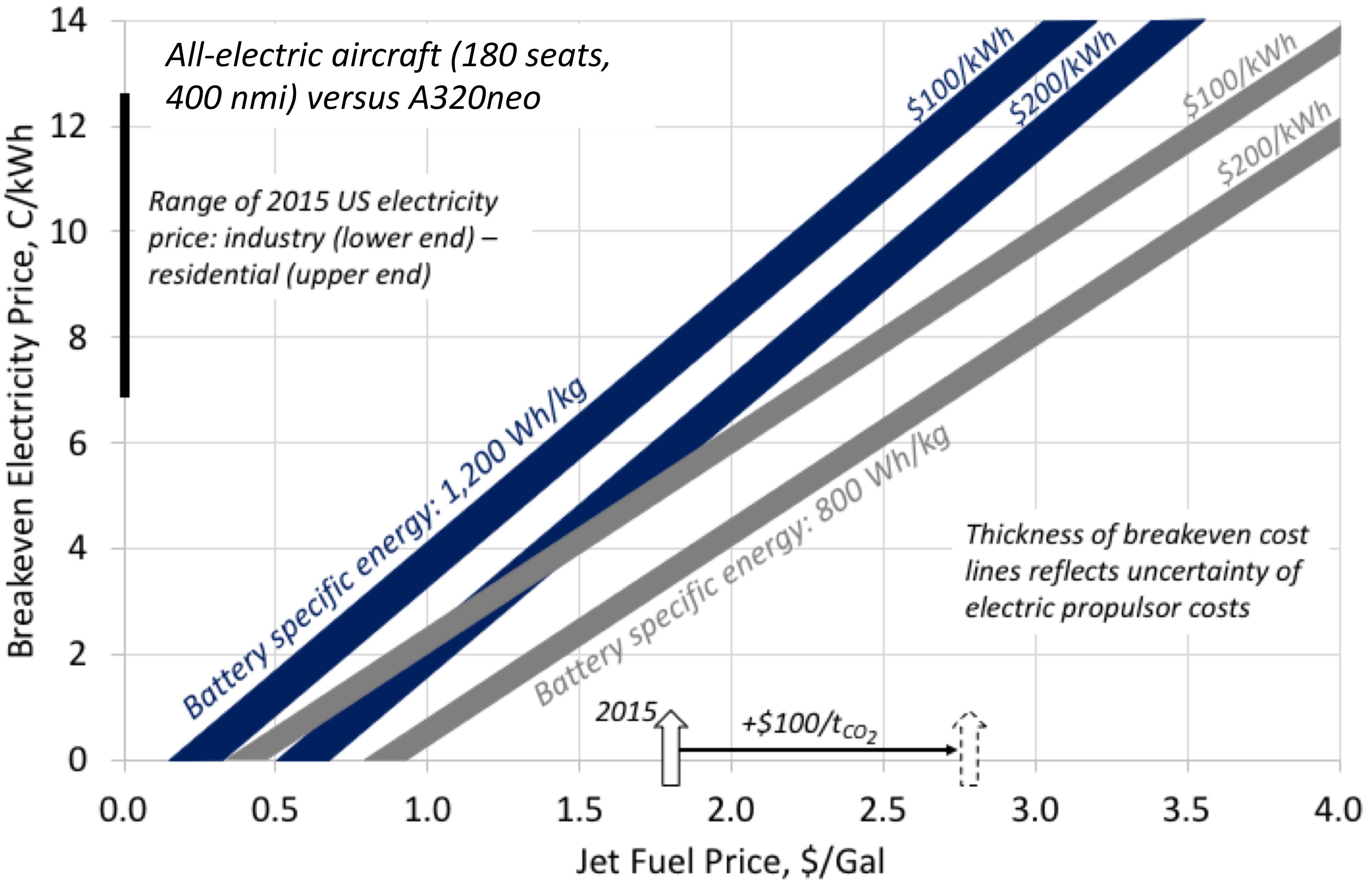
First-Order Cost Analysis



Schäfer A.W., Barrett S.R.H., Doyme K., Dray L.M.D., Gnadt A.R., Self R., O'Sullivan A., Synodinos A.P., Torija A.J., "Energy, Economic and Environmental Prospects of All-Electric Aircraft", forthcoming in *Nature Energy*.

Aviation Integrated Model: Modelling Airline Behavior

- Each airline sequentially maximizes profit (P) within its network (obj. fct.)
- Three decision variables: airfare (F), flight frequency (FF), type of aircraft (a)

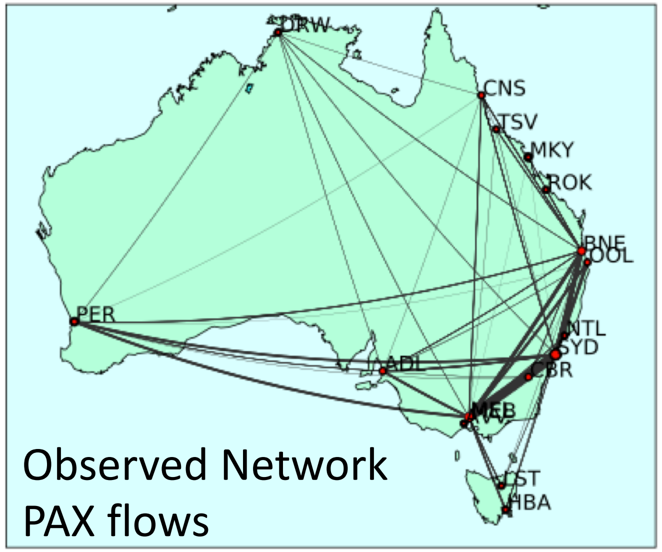
$$P = \underbrace{\sum_{i \epsilon itn}(Itn\ F_i \cdot Itn\ PAX_i)}_{\text{Revenues}} - \underbrace{\sum_{l \epsilon seg}\Big(\sum_{a \epsilon A/C} DOC_{Flight,a,l} \cdot FF_{a,l}\Big)}_{\text{Flight-related costs}} - \underbrace{\sum_{l \epsilon seg}\Big(\sum_{a \epsilon A/C} DOC_{PAX,a,l} \cdot PAX_{a,l}\Big)}_{\text{PAX-related costs}}$$

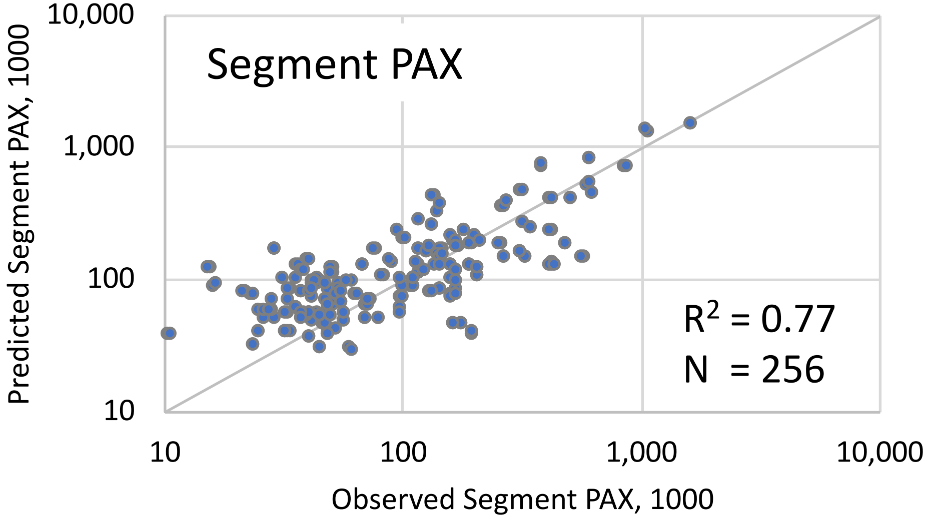
- Set of around 10 linearized constraints
- Iteration until equilibrium
- IBM CPLEX linear programming solver

→ Market size and profit-optimum business model of novel aircraft

Doyme K., Dray L., O'Sullivan A., and Schäfer A.W., 2019. “Simulating Airline Behavior: Application for the Australian Domestic Market“, Transp. Res. Rec., 2673(2), 104-112.

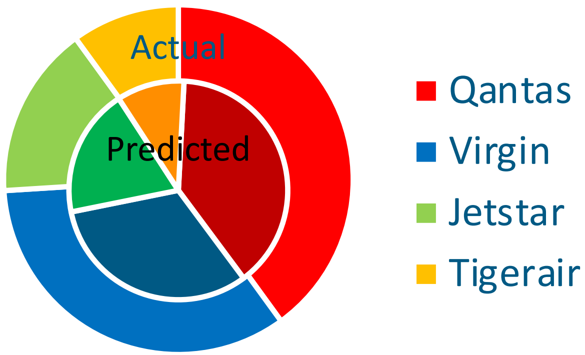
Aviation Integrated Model: Sample Results – Australia

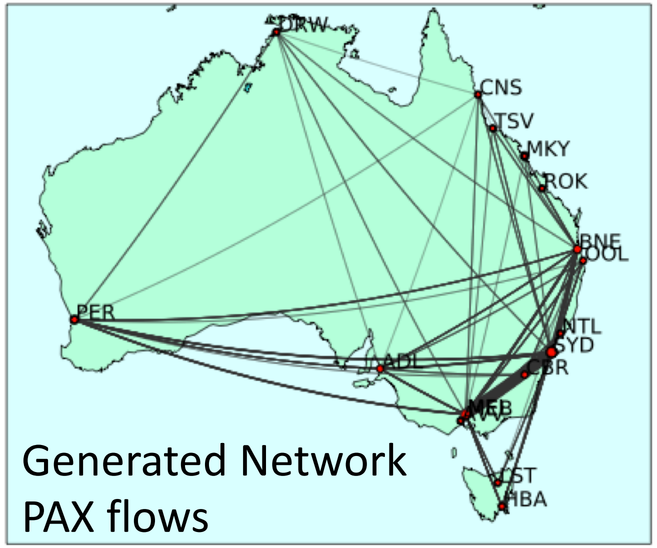


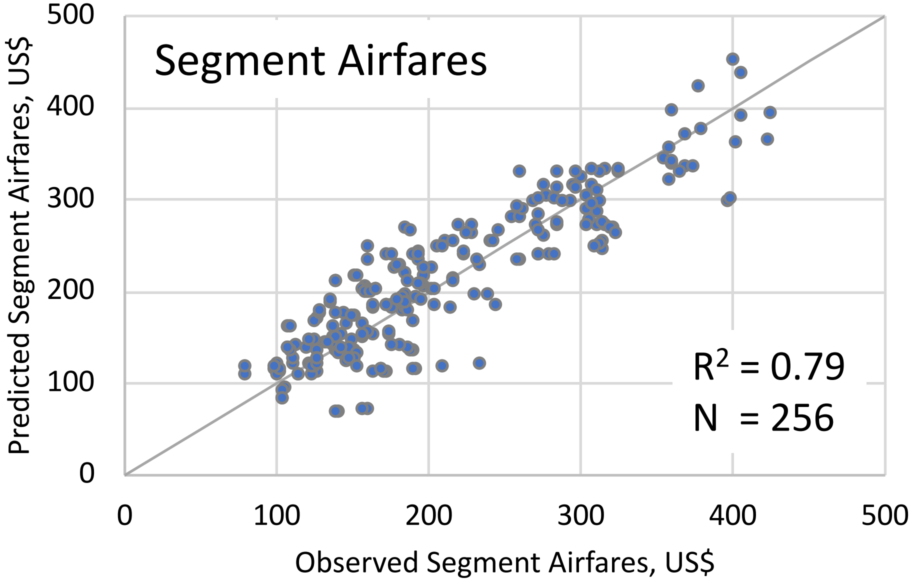


Airline Market Shares

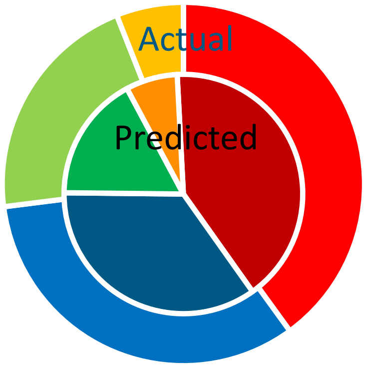
Whole Network







Melbourne to Sydney



Simulating All-Electric Aircraft Adoption / Operation

- 156 PAX all-electric aircraft (techno-econ. characteristics similar to above)
- Airport and en-route charges remain unchanged
- Max. range 400 nmi (741 km), MEL–SYD: 381 nmi (709 km) ≈ 20% of dom. PAX
- 2015 traffic and network
- 4 competing airlines: QANTAS Jetstar Virgin australia tigerair
- Direct operating costs VA, TT < Qanats, JQ

Preliminary Results: % Change to Reference

	Avg. % Change to Reference over Network				Absolute
	Profits	Flight Freq.	PAX	Avg. Fare	El A/C Fleet
QANTAS	-6.6	4.0	-4.6	0.6	17
Jetstar	-11.9	-4.9	-13.2	-0.3	12
Virgin australia	-4.3	16.5	1.3	0.3	21
tigerair	24.1	88.1	41.0	2.2	11