

Revealing the Oil Majors' Adaptive Capacity to the Energy Transition with Deep Multi-Agent Reinforcement Learning

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Outline

Introduction

Solving a Wargame

2DP-MARL

Results & Analysis

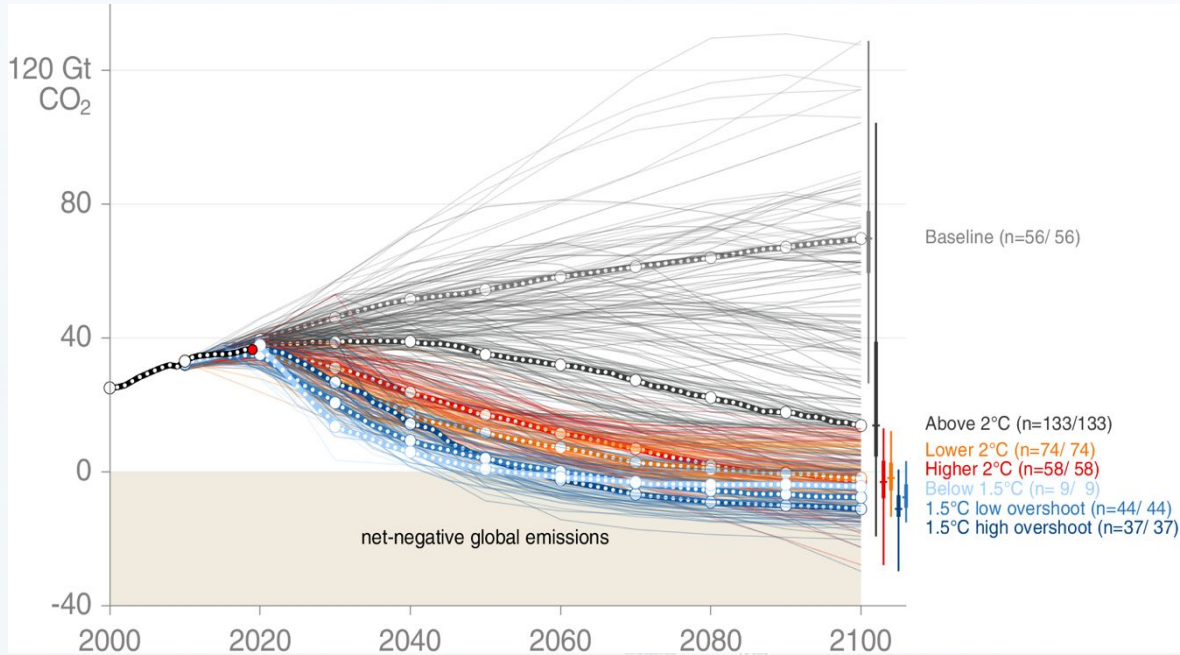
Impact

Future Work



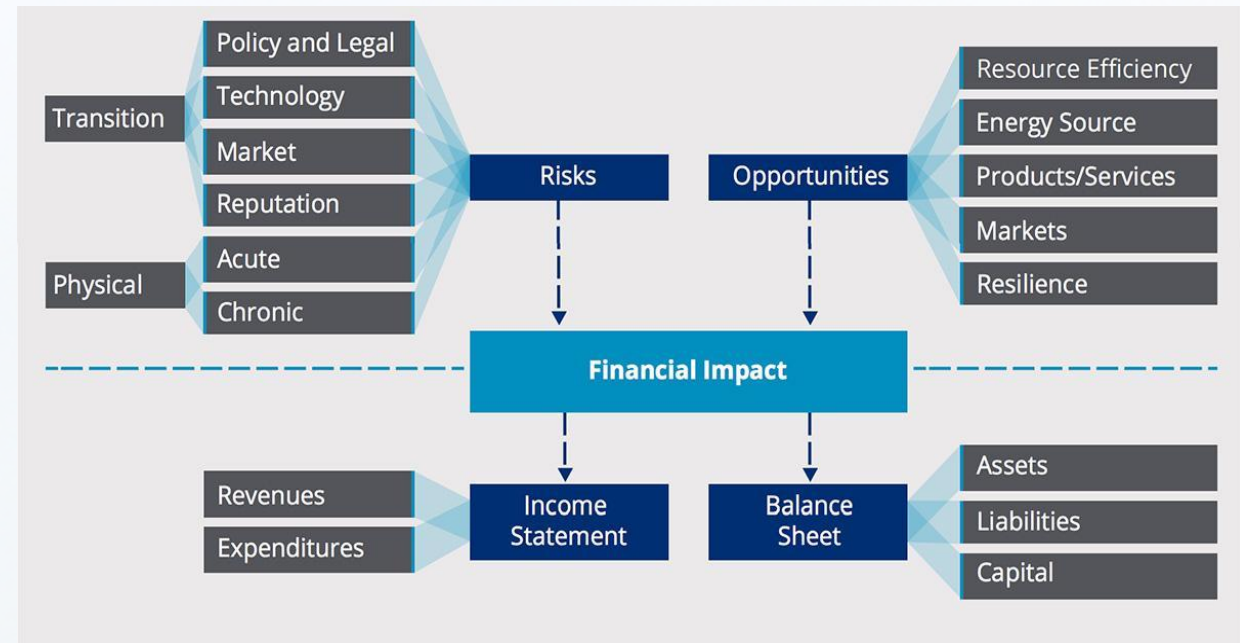
Introduction





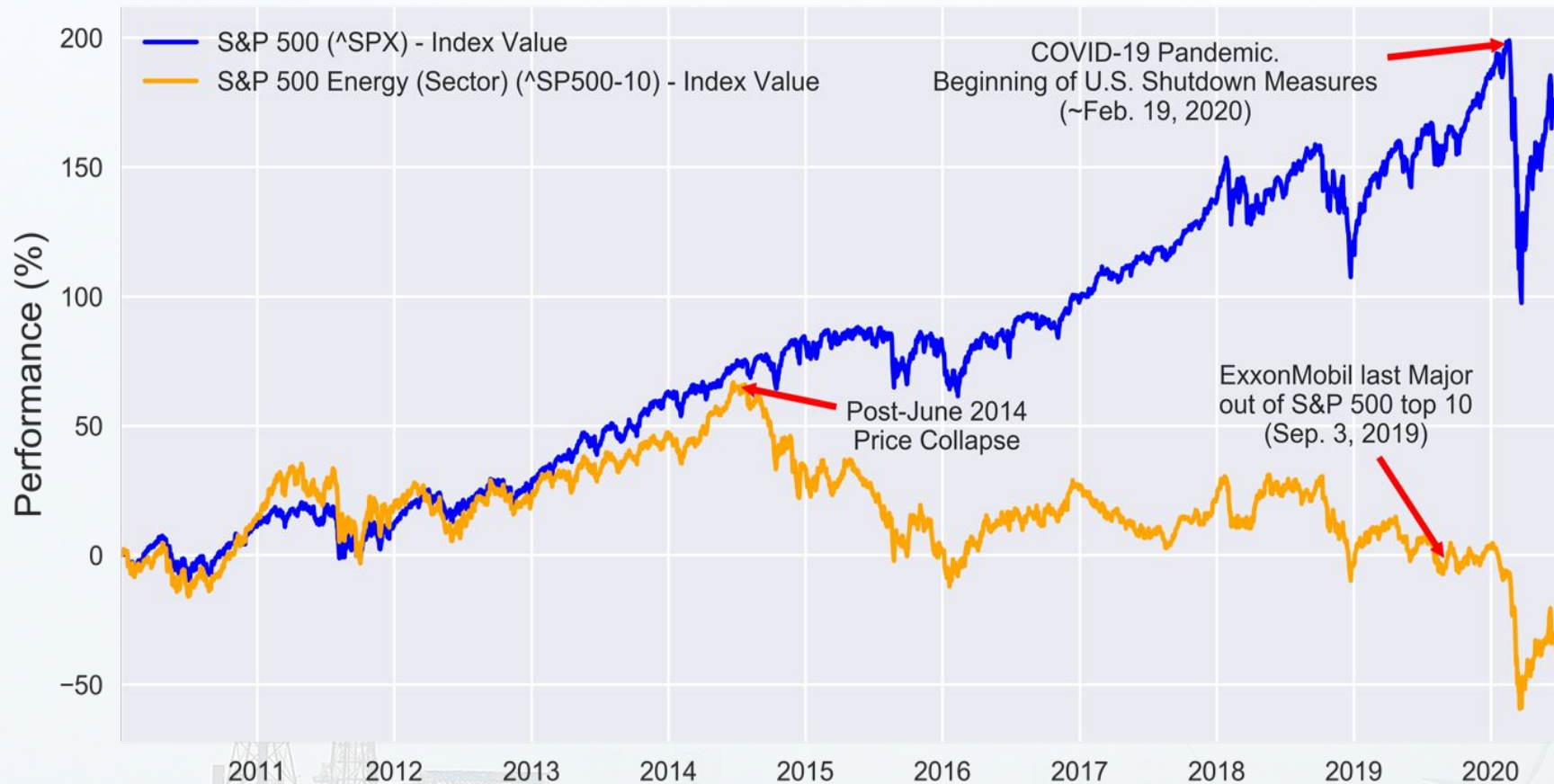
Energy transition manifesting in response to climate change

- Though pathways vary, all scenarios predicated on low-carbon energy production
- Deep decarbonization requires massive reallocation of capital



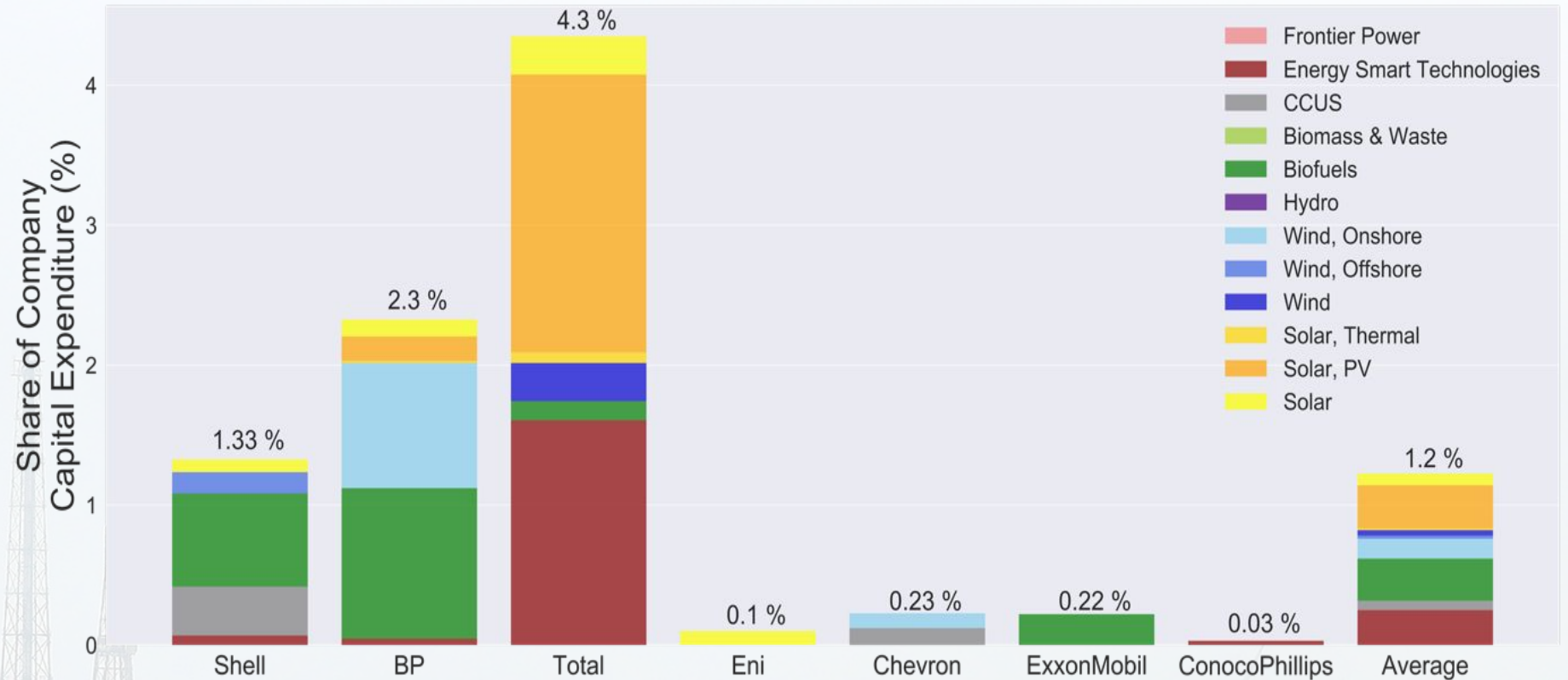
Transition risks will arise, however, so will opportunities

- Rapid low-carbon transition poses an existential threat for the fossil fuel industry, particularly the oil Majors
- Adaptation may prove financially favorable



The Majors have been in decline since 2014, COVID-19 has accelerated it

- Oil & gas companies have consistently underperformed despite economic growth
- Financial recovery post-COVID through BAU becomes increasingly unlikely as the impending energy transition unfolds



Low-carbon actions speak louder than net-zero words

- Majors have set out plans for a full-scale decarbonization of their business models
- Throughout the previous decade, the Majors' low-carbon efforts proved minimal
- Majors have yet to make significant moves into low-carbon business models as the upside and downside risks of doing so remain unclear

Aim

Provide tangible insights into the Majors' adaptive capacity to the energy transition by

Exploring upside and downside risks of a first low-carbon mover

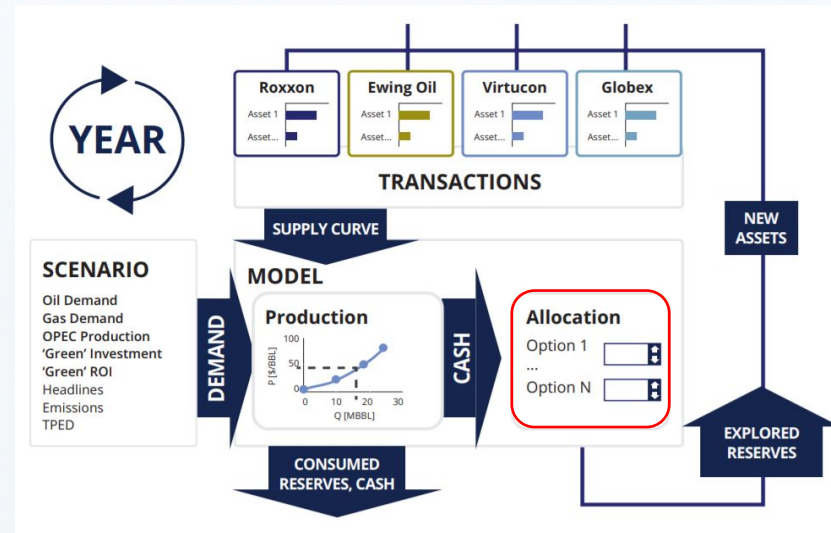
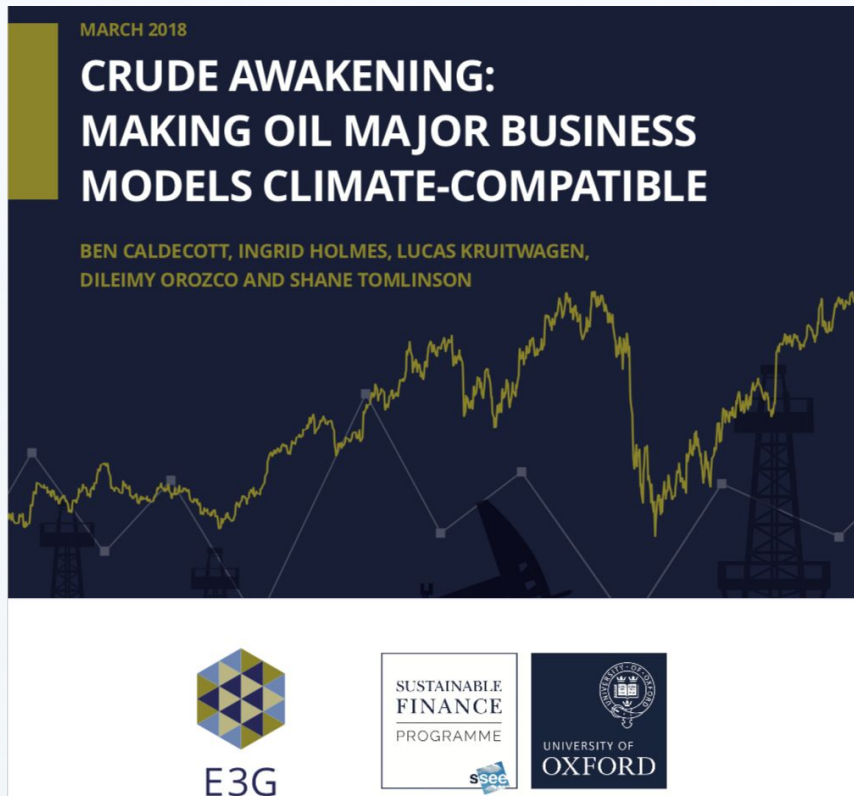


Solving for robust business pathways amidst energy transition uncertainty

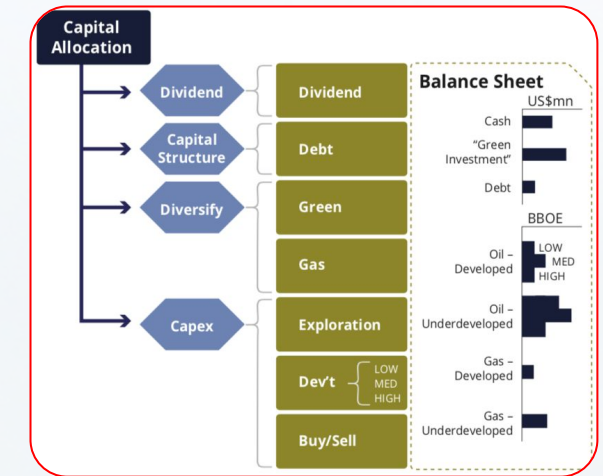


Solving a Wargame





2DP Wargame Schematic



Player Allocation Options

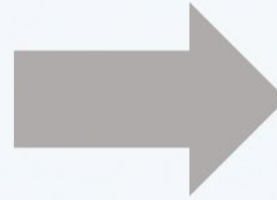
2 Degrees Pathways Wargame – testbed for oil & gas transition

- The 2 Degrees Pathways (2DP) wargame created to
“To help inform company, investor, government, and civil society thinking around pathways the oil and gas majors can take to become 1.5C/2C-compatible”
- Originally played with human players, revealing more about human bias than robust, climate-compatible pathways

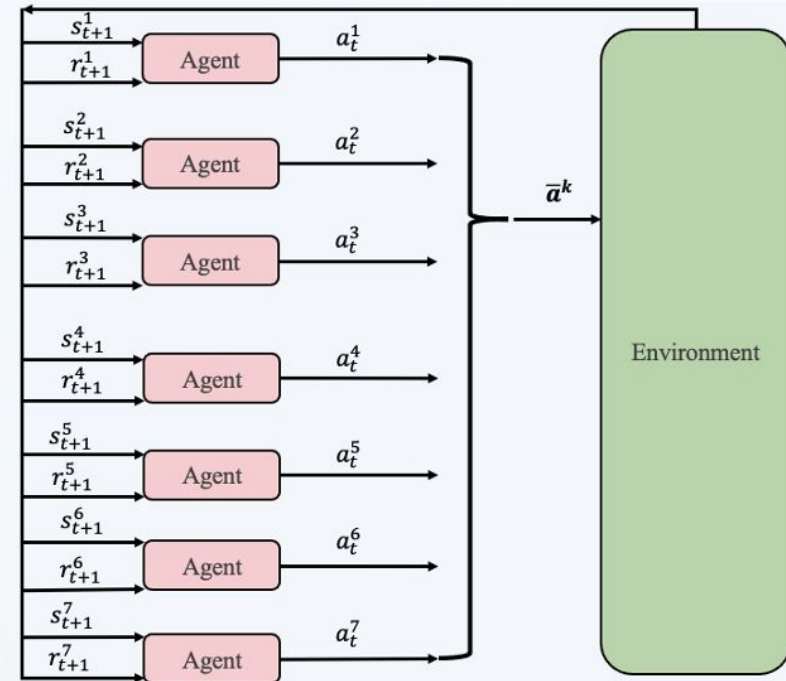
Partially Observable Stochastic Game

$$\langle \mathcal{I}, \mathcal{S}, \{b^0\}, \{A_i\}, \{\mathcal{O}_i\}, \mathcal{P}, \{\mathcal{R}_i\} \rangle$$

Notation	Description
\mathcal{I}	Finite set of agents indexed 1, ..., n
\mathcal{S}	Finite set of states $\{s^1, \dots, s^N\}$
$b^0 \in \Delta(\mathcal{S})$	Initial state distribution
A_i	Finite set of actions available to agent i and $\vec{A} = \times_{i \in \mathcal{I}} A_i$ is the set of joint actions (i.e. action profiles), where $\vec{a} = \langle a_1, \dots, a_n \rangle$ denotes the joint action
\mathcal{O}_i	Finite set of observations for agent i and $\vec{\mathcal{O}} = \times_{i \in \mathcal{I}} \mathcal{O}_i$ is the set of joint observations where $\vec{o} = \langle o_1, \dots, o_n \rangle$ denotes the joint observation
\mathcal{P}	Set of Markovian state transition and observation probabilities, where $\mathcal{P}(s', \vec{o} s, \vec{a})$ denotes the probability that taking joint action \vec{a} in state s results in a transition to state s' and joint observation \vec{o}
$\mathcal{R}_i: \mathcal{S} \times \vec{\mathcal{A}}$	Reward function for agent i



Multi-Agent Reinforcement Learning



Framing 2DP as a Partially Observable Stochastic Game

- A continuous control problem with multiple competing entities, 2DP is best characterized as a Partially Observable Stochastic Game (POSG)—a Markovian framework resemblant of real-life market competition

Solving with Deep Multi-Agent Reinforcement Learning

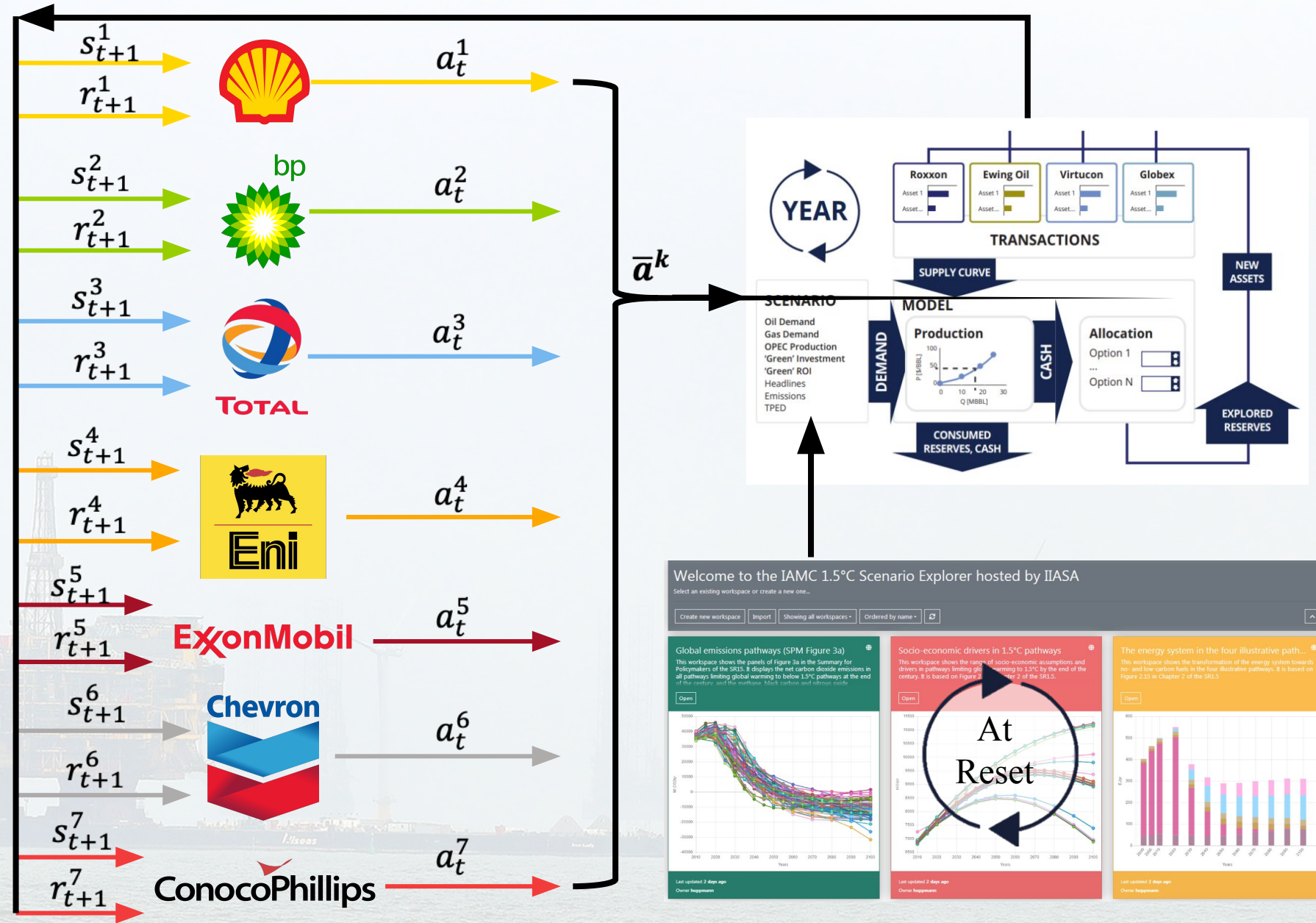
- Advances in Deep Multi-Agent Reinforcement Learning (MARL) have achieved superhuman-level performance in POSGs of high-dimensional settings

2DP-MARL



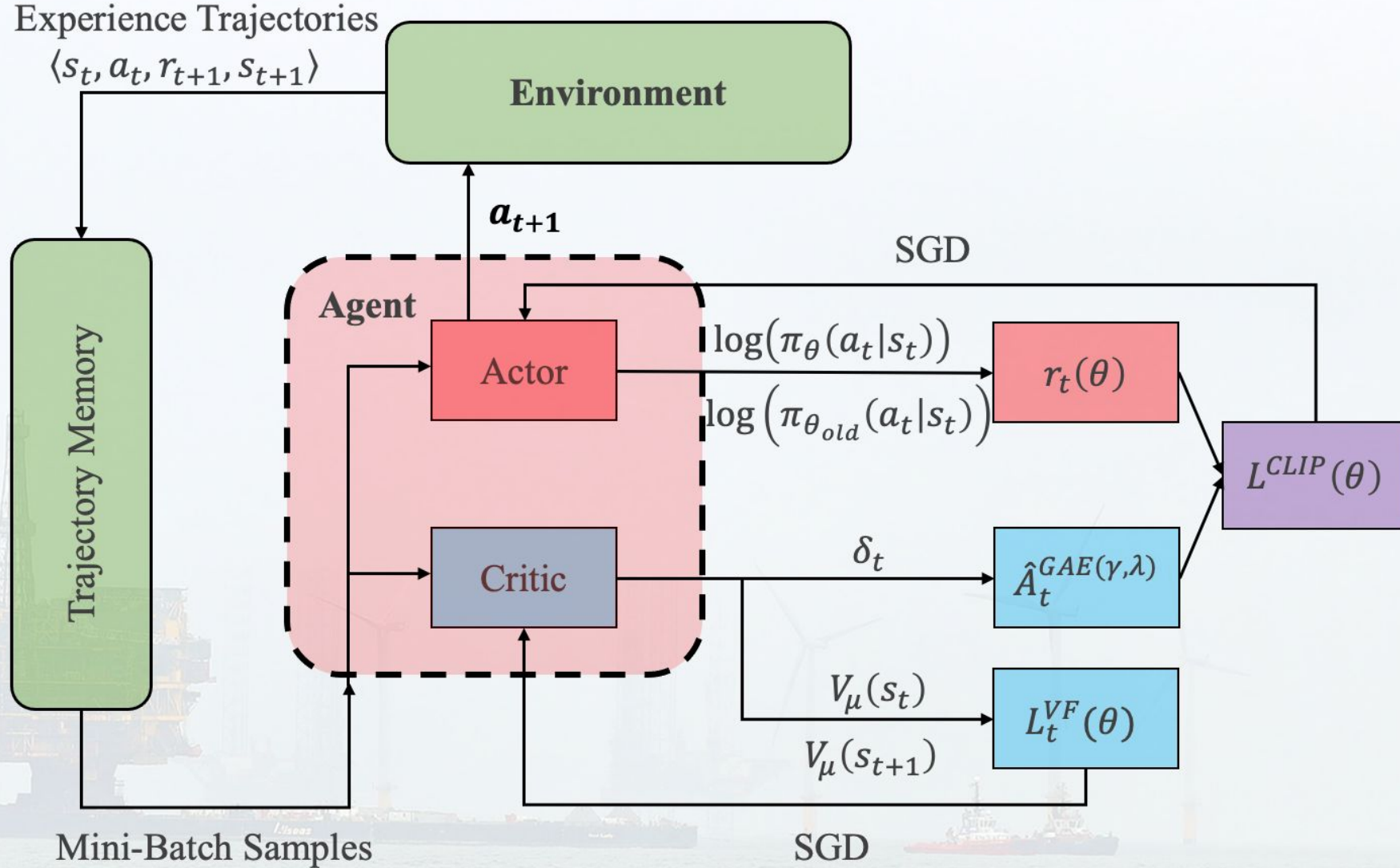
A novel microeconomics model relevant to the energy transition discussion

- 2DP-MARL combines wargaming and advances in Deep MARL to help guide the Majors' stakeholders in assessing climate-compatible business models



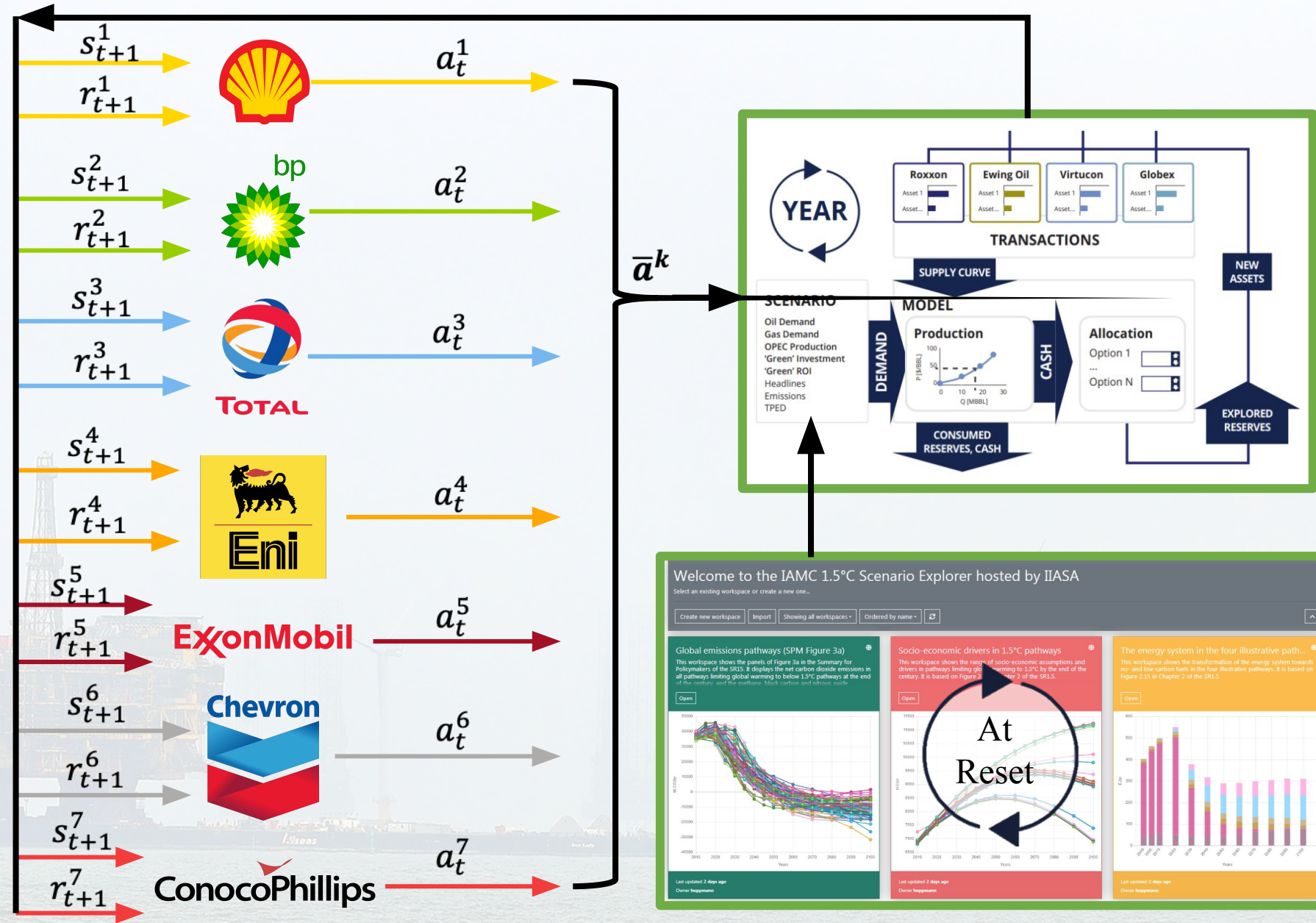
A2C/PPO as foundational algorithms

- Algorithms employed take from Advantage Actor-Critic and Proximal Policy Optimization to solve a game in a high-dimensional, continuous space



Environment

- Original 2DP Wargame, 2020-2040
- Climate-compatible scenario data generated from Integrated Assessment Modeling Consortium (IAMC) and International Institute for Applied Energy Systems (IIASA) ensemble

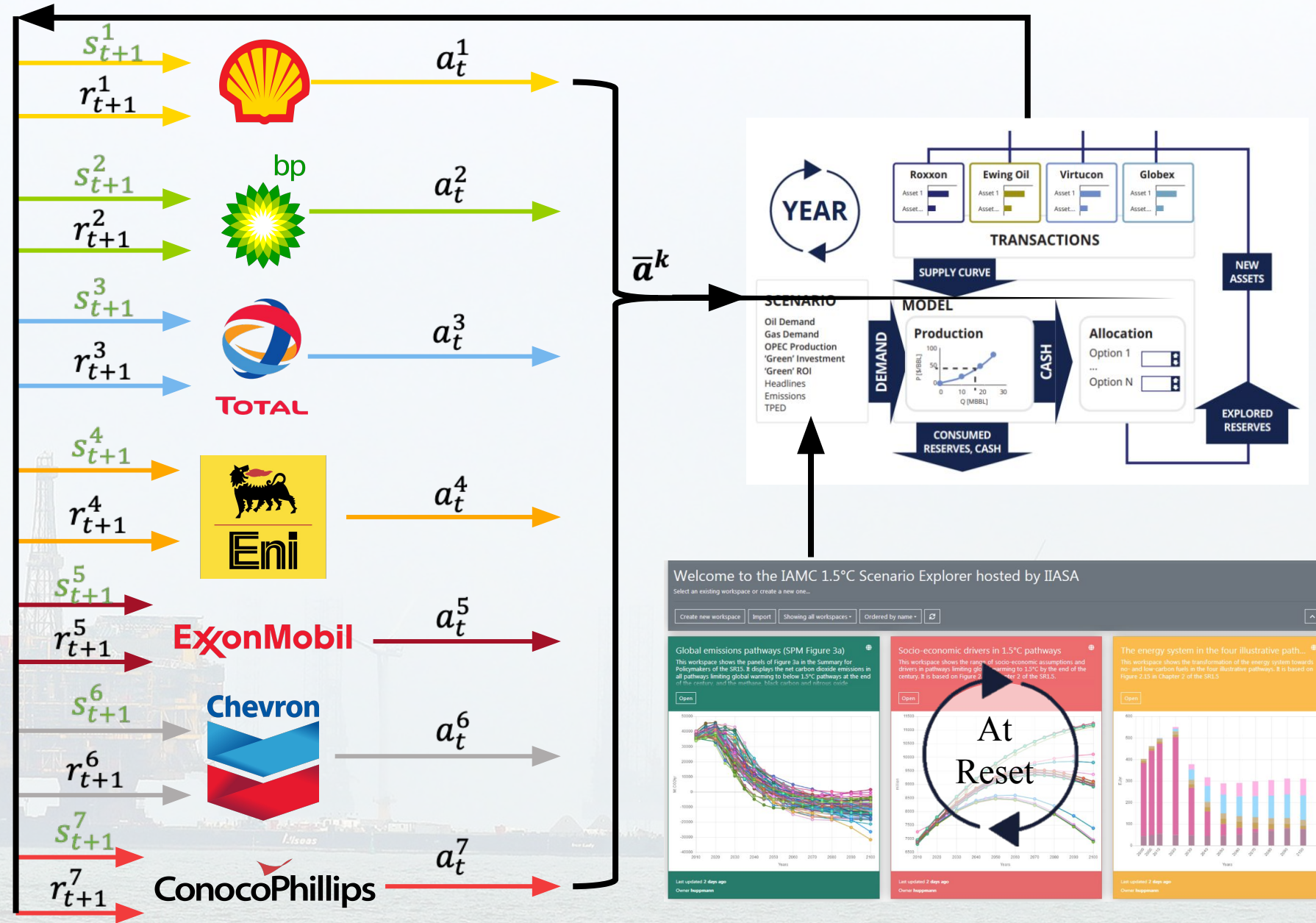


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Observations

- Incomplete information to mimic real-life competition (i.e. players may only view some of their adversaries' assets)



Environment

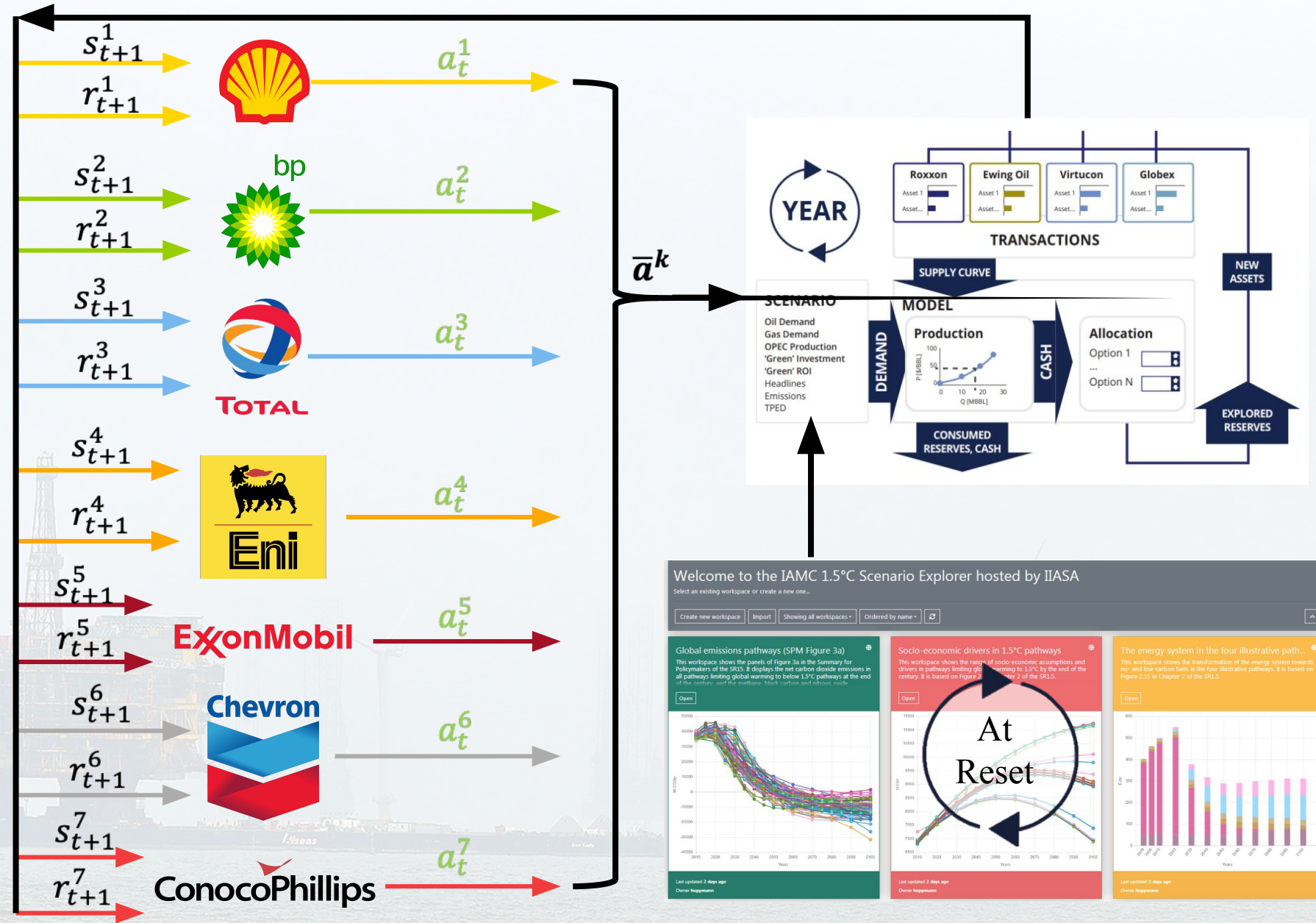
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Actions

- Similar to 2DP wargame capital allocation options, includes player-to-player trading and 'green' auction house



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Observations

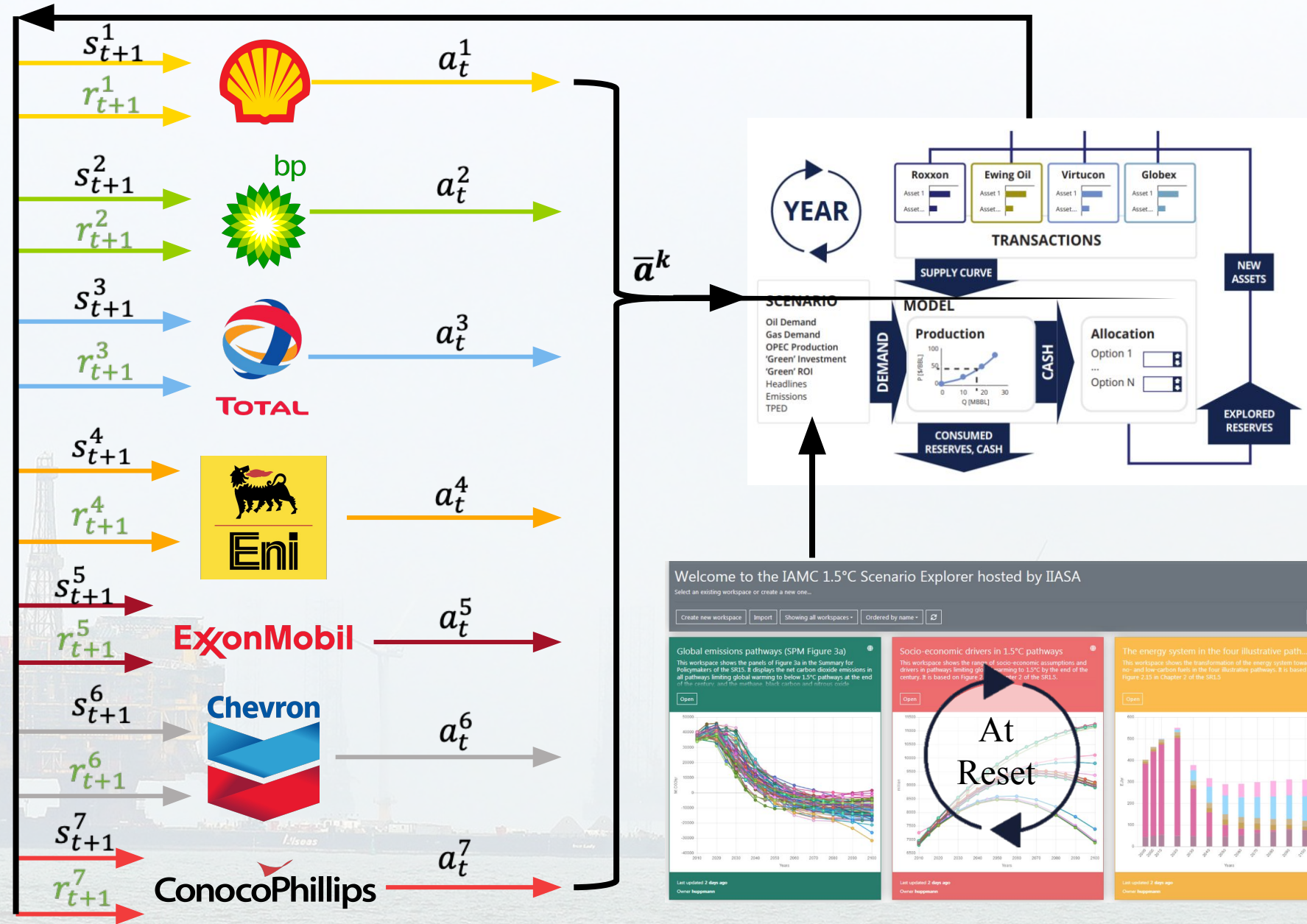
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Rewards

- Focus on maximizing shareholder value through dividends
- Negative rewards to enforce realistic behavior

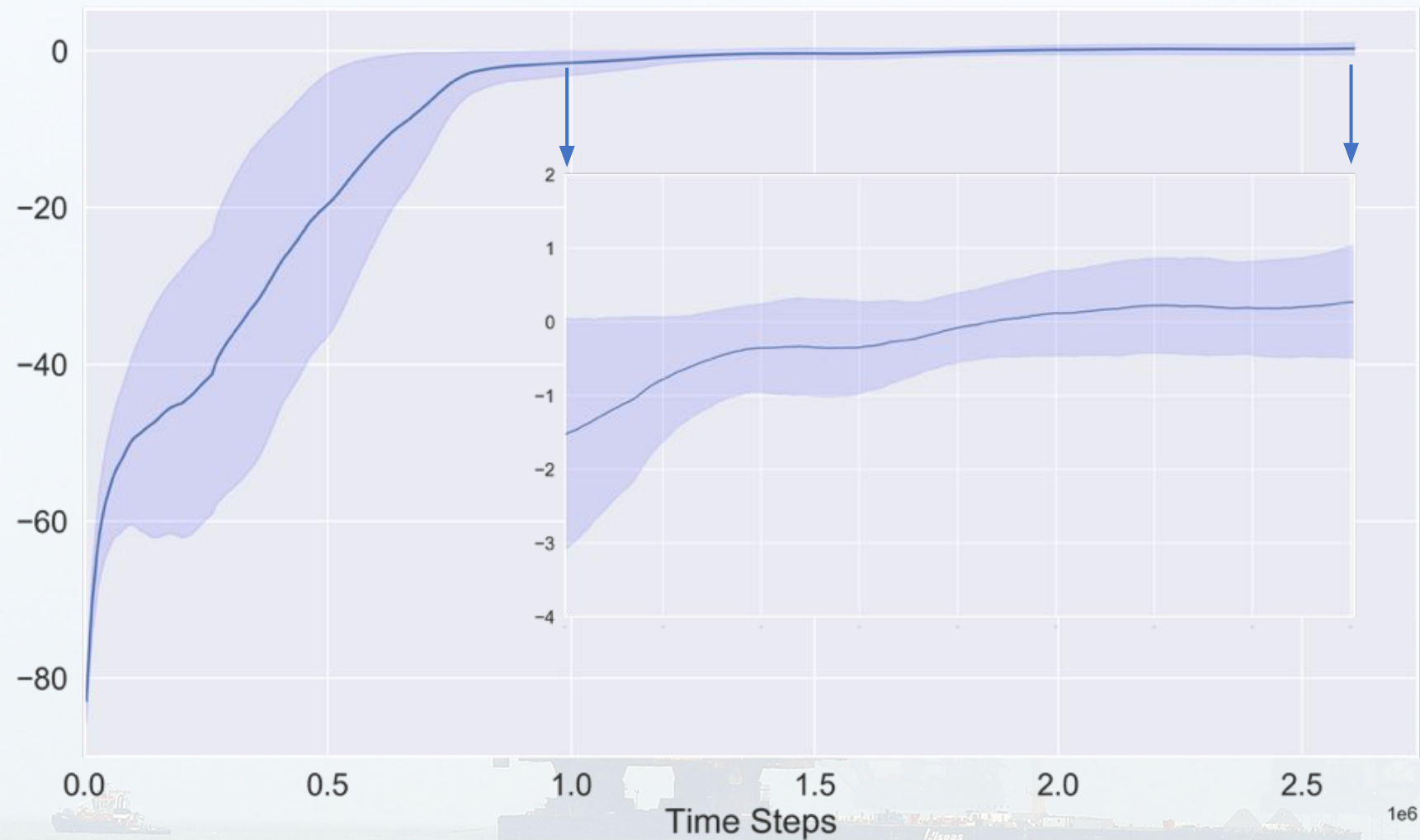


Company: 0 Shell		Assets On Hand (post-allo)										Pipeline Assets (Final All)										Pipeline Assets (Begin Dev)										Pipeline Assets (Begin Exp)									
year	Cash(\$)	Debt(\$)	Undr.	Undr.	Undr.	Devl.	DevM	DevH	p_Undr.	p_UndM	p_UndH	p_DeVL	p_DeVM	p_DeVH	p_Undr.	p_UndM	p_UndH	p_DeVL	p_DeVM	p_DeVH	p_Undr.	p_UndM	p_UndH	p_DeVL	p_DeVM	p_DeVH	p_Undr.	p_UndM	p_UndH	p_DeVL	p_DeVM	p_DeVH	p_Undr.	p_UndM	p_UndH	p_DeVL	p_DeVM	p_DeVH			
2019	1062871	689556	0	0	0	0	0	0	205	410	615	0	0	0	205	410	615	410	820	1230	205	410	615	410	820	1230	689	1368	2052	2317	4635	6953	8850	17700	26550	3299	4949	7001			
2020	1339661	1447823	0	0	0	0	0	0	205	410	615	410	820	1230	205	410	615	410	820	1230	689	1368	2052	2317	4635	6953	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001			
2021	4538608	4909545	0	0	0	410	820	1230	829	1659	2489	615	1230	1845	684	1368	2052	820	1640	2460	2317	4635	6953	1649	3299	4949	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001			
2022	17330670	18277687	0	0	0	0	615	1230	1845	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460	2460			
2023	62799716	66527384	0	0	0	820	1640	2460	2317	4635	6953	1649	3299	4949	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001			
2024	222723595	237279480	0	0	0	1649	3299	4949	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001	8850	17700	26550	3299	4949	7001			
2025	783210110	837134556	0	0	0	2333	4667	7001	32069	64139	96208	4651	9383	13954	113737	227474	341211	13501	27003	48505	399958	799916	1199874	45571	91142	136714	1397321	2794642	4191963	159308	318617	477925	4863097	9726195	14589293	559266	1118533	1677800			
2026	2736275636	2931287968	0	0	0	4651	9383	13954	113737	227474	341211	13501	27003	48505	399958	799916	1199874	45571	91142	136714	1397321	2794642	4191963	159308	318617	477925	4863097	9726195	14589293	559266	1118533	1677800	16066933	33813867	50720801	58760684	117521369	176282054			
2027	9523060807	10216316617	0	0	0	13501	27003	46515	399958	799916	1199874	45571	91142	136714	1397321	2794642	4191963	159308	318617	477925	4863097	9726195	14589293	559266	1118533	1677800	16066933	33813867	50720801	58760684	117521369	176282054	183486761082	206973522164	310460283246	4092434541	10389701812	183486761082			
2028	33107654831	35539445568	0	0	0	45571	109748	183229	1397321	2794642	4191963	159308	318617	477925	4863097	9726195	14589293	559266	1118533	1677800	16066933	33813867	50720801	58760684	117521369	176282054	183486761082	206973522164	310460283246	4092434541	10389701812	183486761082	206973522164	310460283246	4092434541	10389701812	183486761082				
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Game Info		Policies										Financial and Industry Metrics										Dividend Metrics										Cost of Capital (%)									
year	O_Pri	Brrw	P_Div	P_Debt	Upd_L	Upd_M	Upd_H	Exp_0	Exp_1	Div(\$)	Debt(\$)	Dev_L(\$)	Dev_M(\$)	Dev_H(\$)	Exp_0(\$)	Exp_1(\$)	TEV(\$)	ROI(%)	RDE(%)	D/E(%)	R/P	Cost of Capital (%)	Div(\$)	Debt(\$)	Dev_L(\$)	Dev_M(\$)	Dev_H(\$)	Exp_0(\$)	Exp_1(\$)	TEV(\$)	ROI(%)	RDE(%)	D/E(%)	R/P							

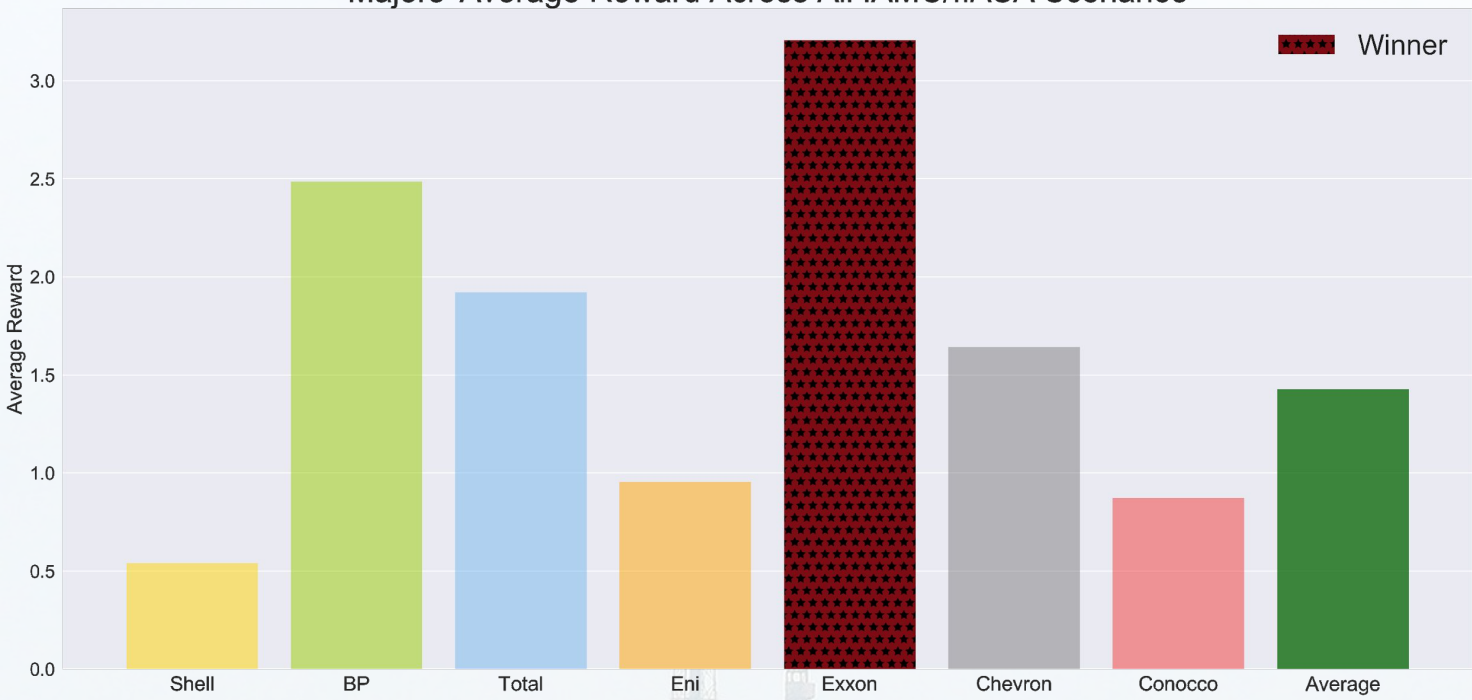
Results & Analysis





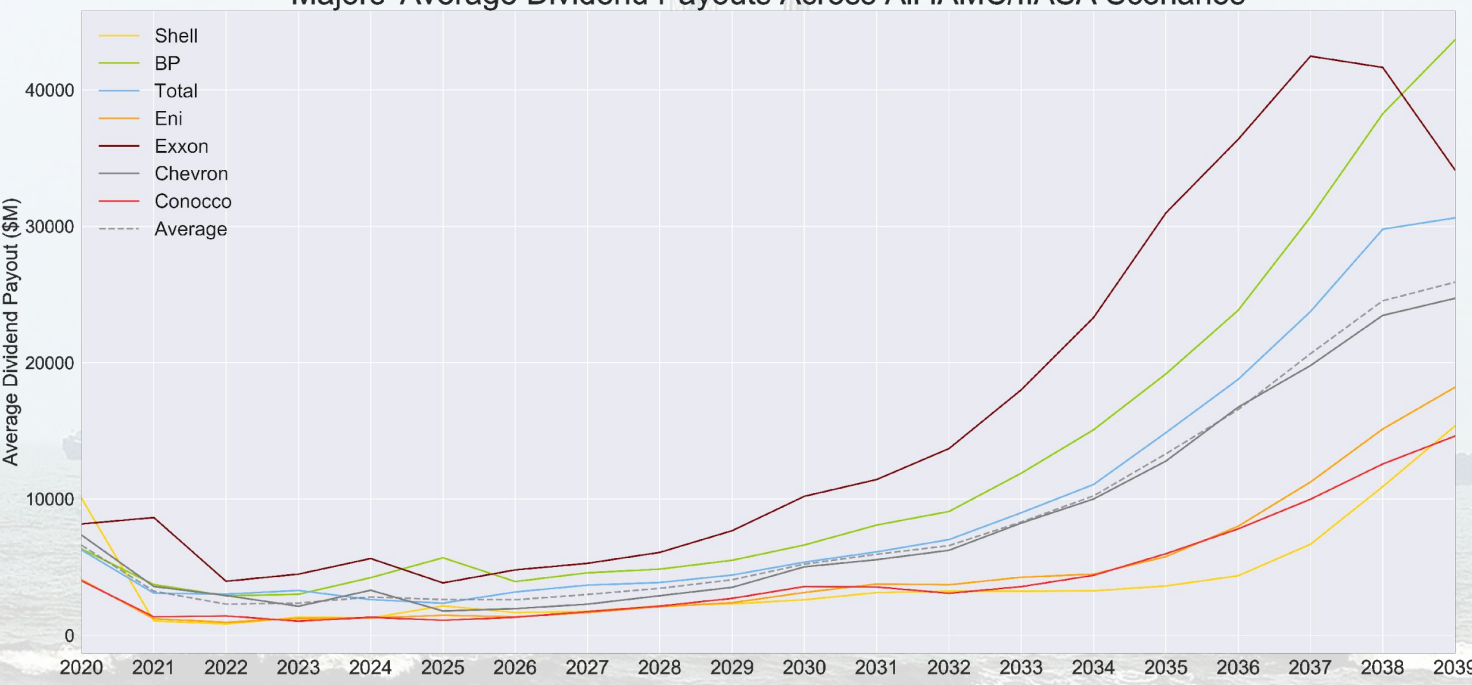
- Convergence towards a scenario-robust solution is reached after ~ 2.6 M timesteps, or 320 pass throughs each scenario ($\sim 130,000$ games played)
- Convergence towards a positive reward indicates agents achieved realistic, robust strategies to maximize dividend payouts
- Oil and gas, 'green' and debt holdings are explored to evaluate the Majors' business models

Majors' Average Reward Across All IAMC/IIASA Scenarios

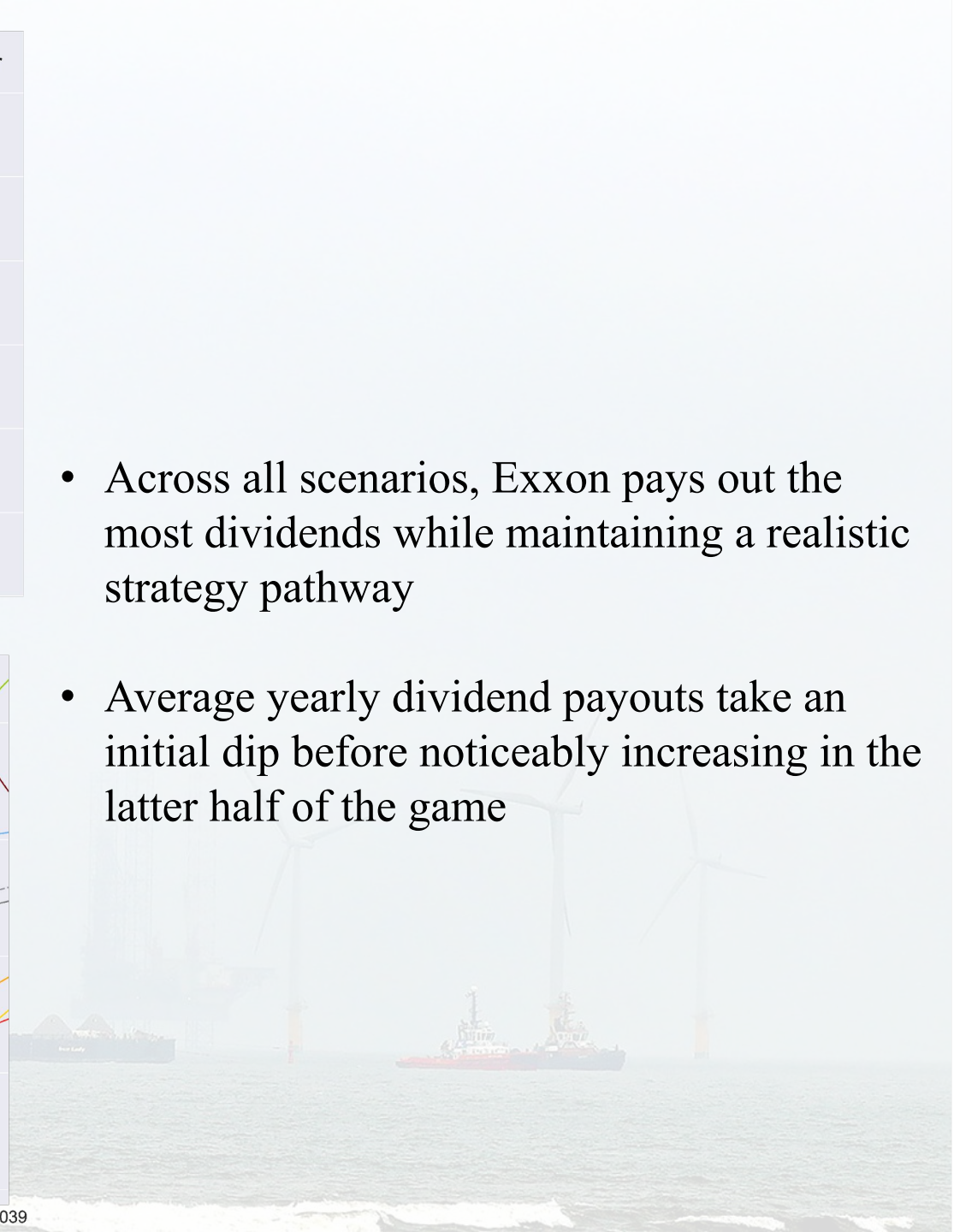


- Across all scenarios, Exxon pays out the most dividends while maintaining a realistic strategy pathway

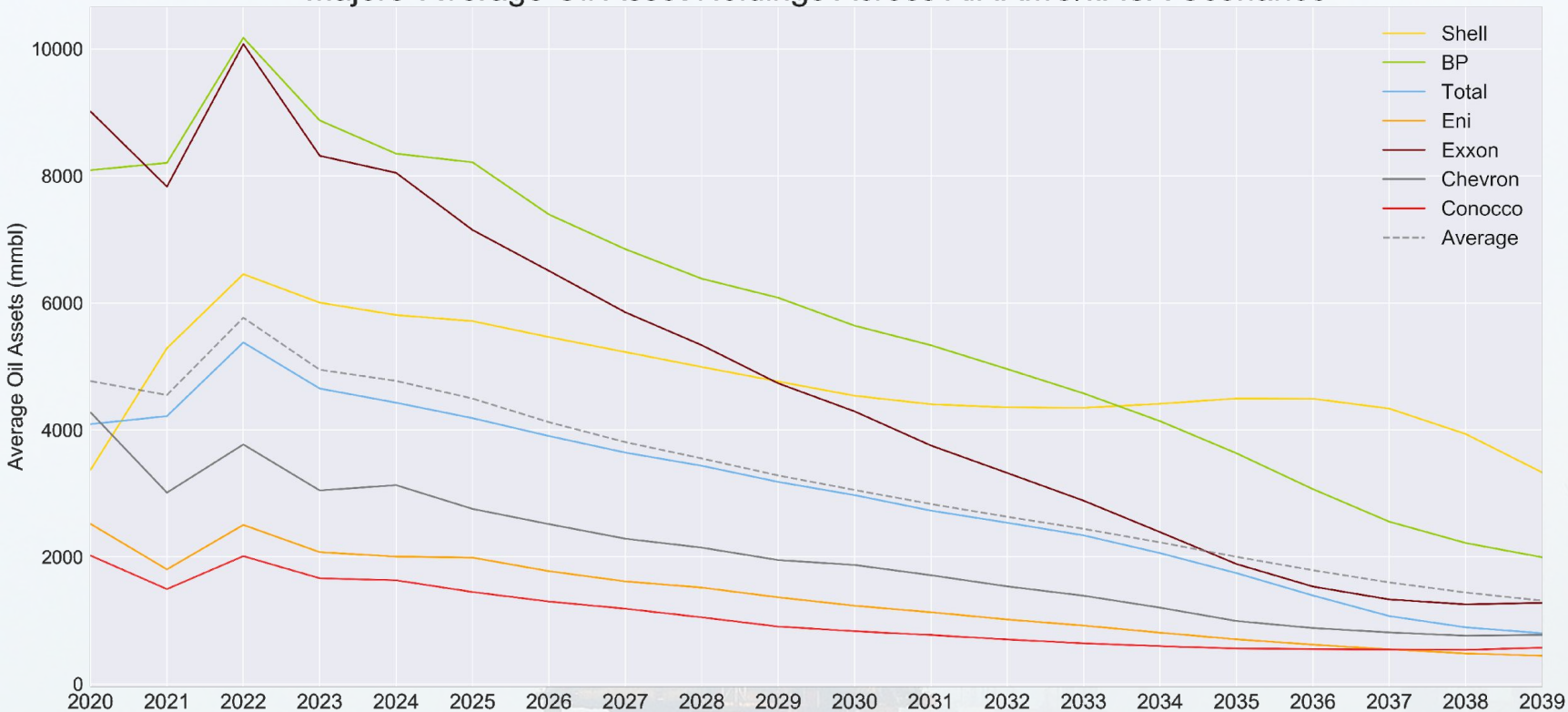
Majors' Average Dividend Payouts Across All IAMC/IIASA Scenarios



- Average yearly dividend payouts take an initial dip before noticeably increasing in the latter half of the game

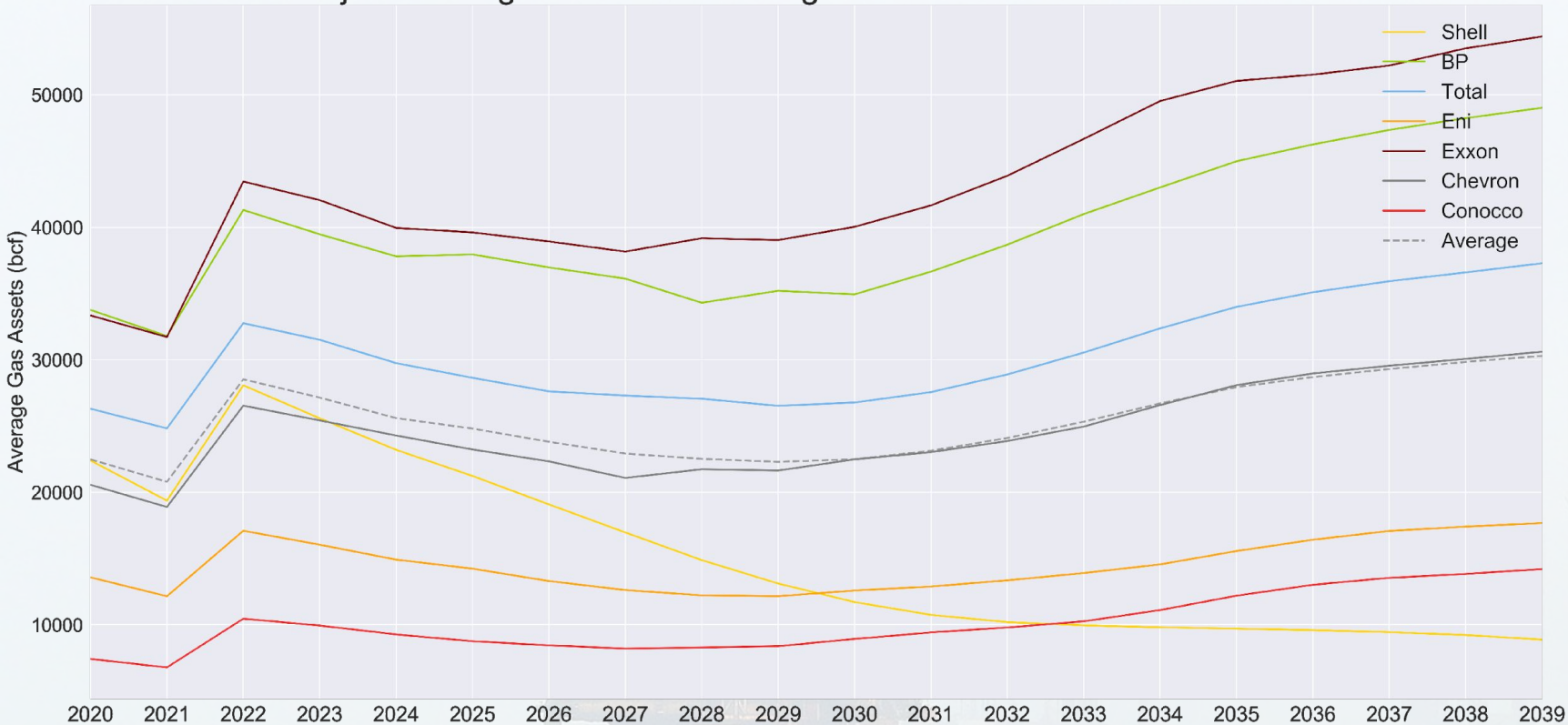


Majors' Average Oil Asset Holdings Across All IAMC/IIASA Scenarios



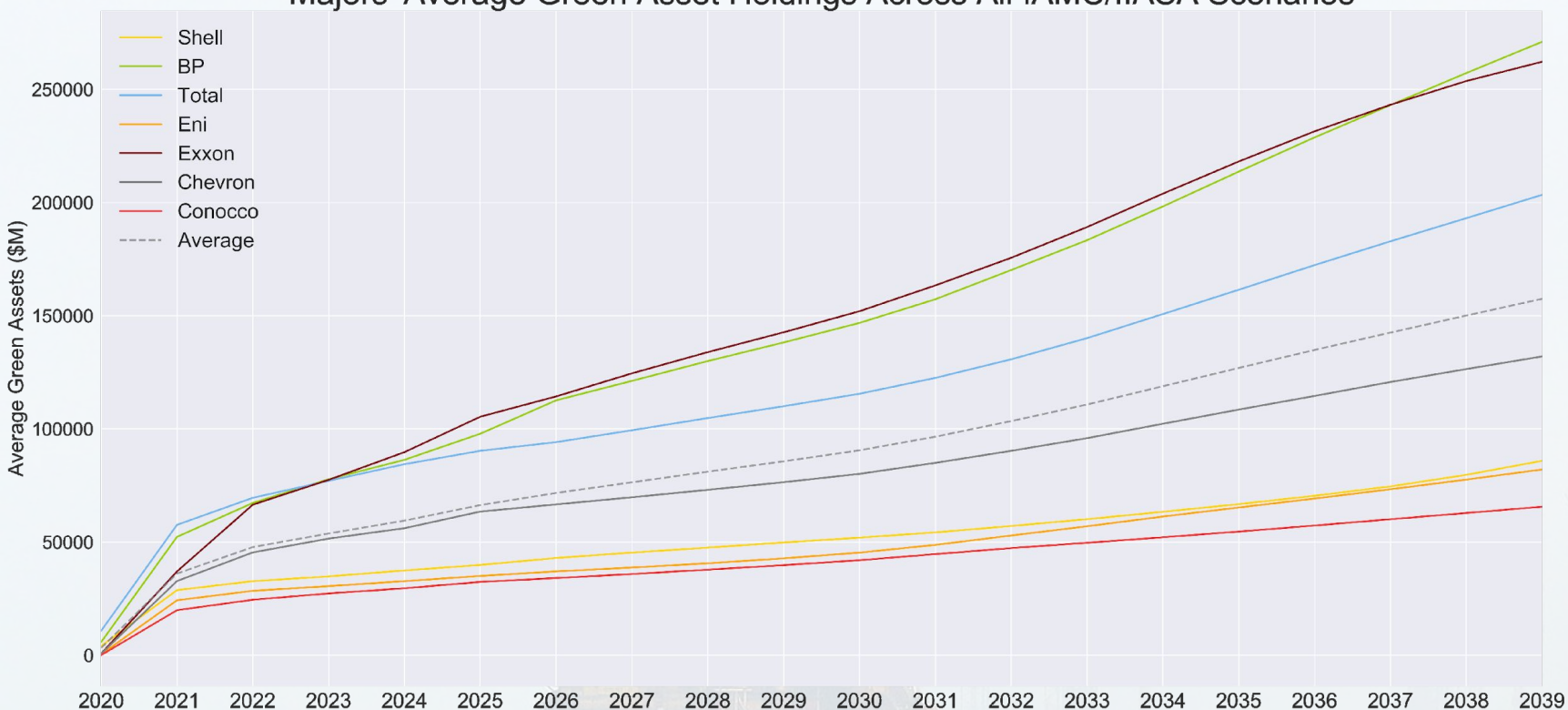
- Majors heavily divest from oil assets early, continue divestment throughout
- Shell and BP maintain the greatest oil market share at the end game

Majors' Average Gas Asset Holdings Across All IAMC/IIASA Scenarios



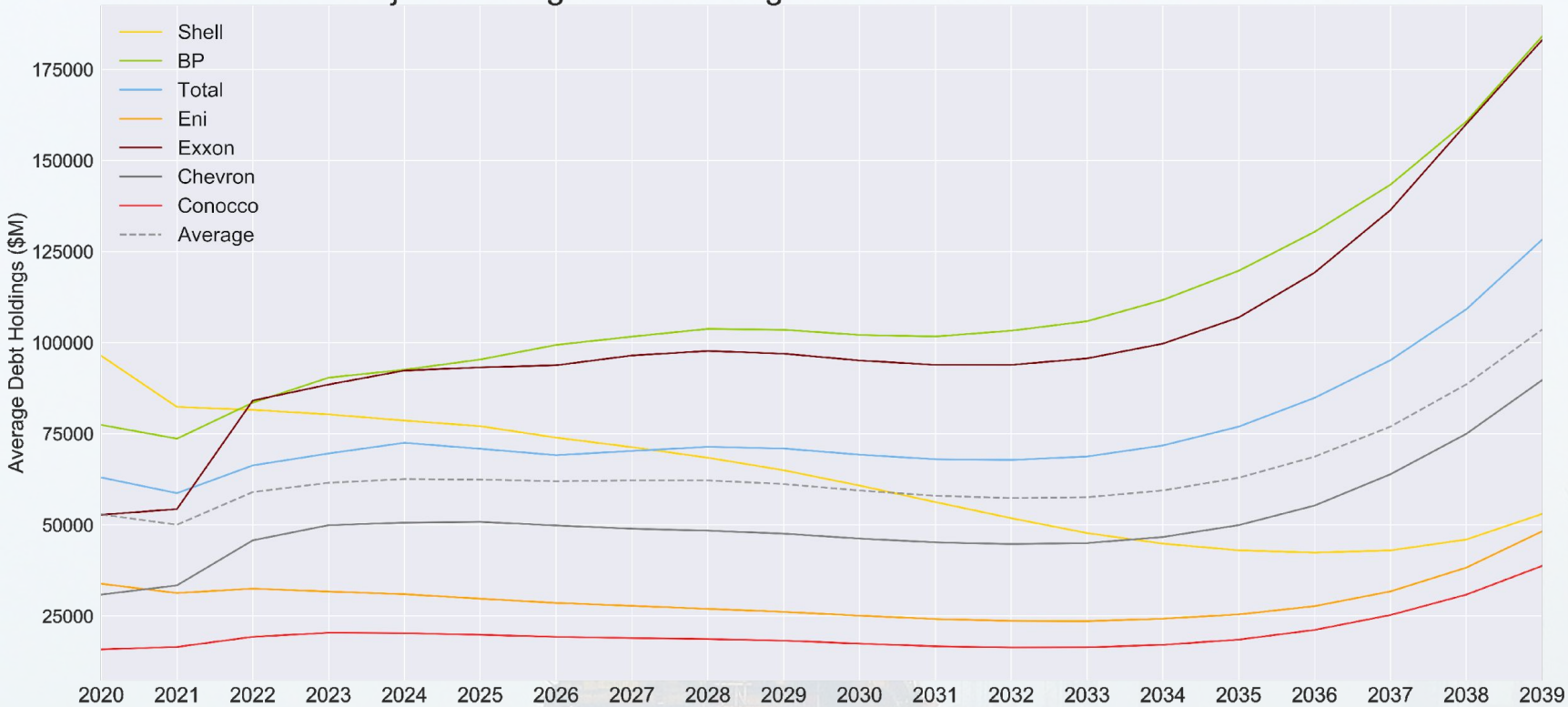
- Majors gradually increase gas asset holdings, suggesting the carbon asset's net income stability
- Gas market shares remain similar, however, Shell tends to let its market share slip

Majors' Average Green Asset Holdings Across All IAMC/IIASA Scenarios



- Majors heavily invest in ‘green’ assets; display similar ‘first-mover’ behavior and long-term trends
- Exxon and BP act as leaders of the ‘green’ movement primarily due to their large, initial balance sheets

Majors' Average Debt Holdings Across All IAMC/IIASA Scenarios



- Hints of a leverage transition (i.e. borrowing cash to buy ‘green’ assets) undertaken by BP and Total, Exxon and Chevron.
- Levels of debt increase towards the end game due to Majors’ new debt resilience

Impact



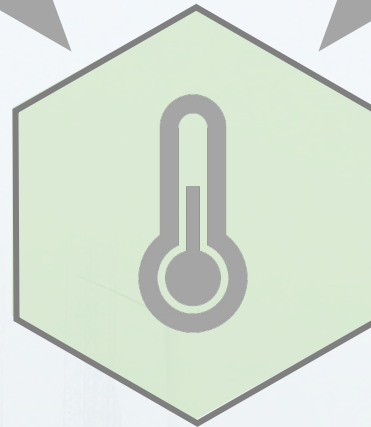
Moving First, Benefits Outweigh Costs

Moving first into 'green' assets allows Majors to accumulate higher returns long-term and maintain stable levels of debt



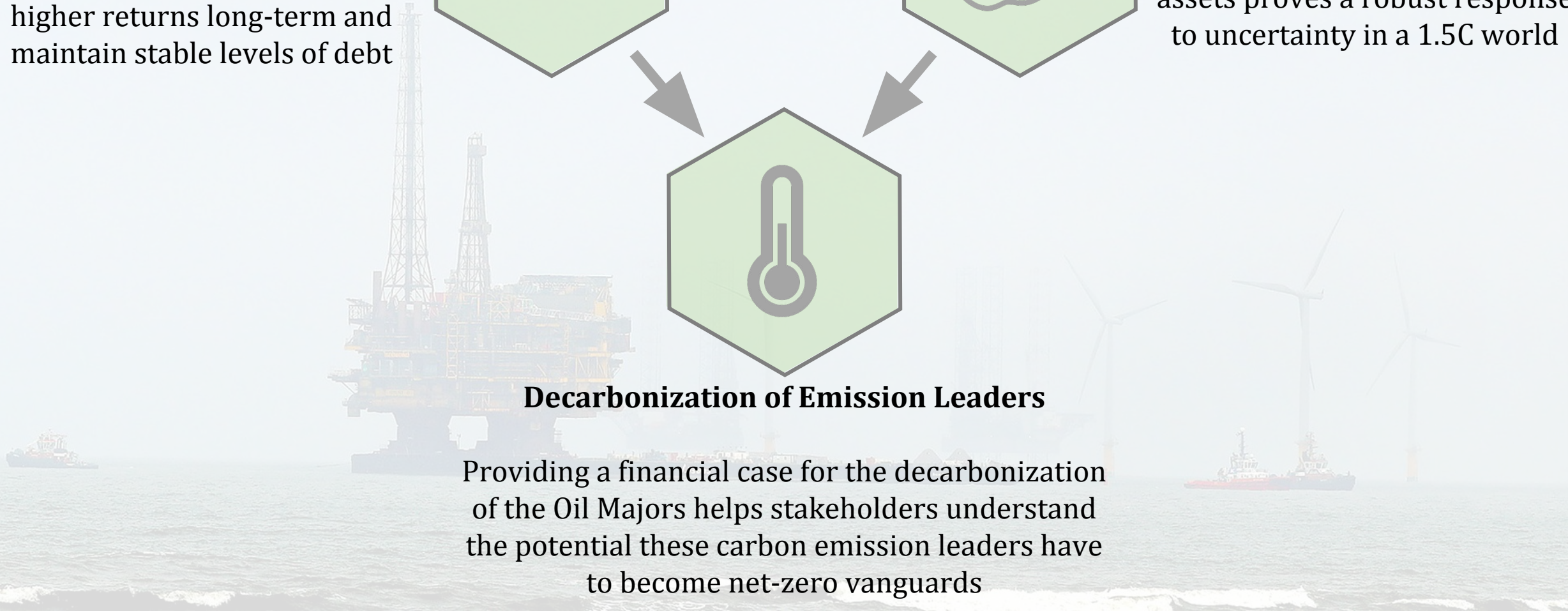
A Robust, 'Green' Strategy

Going 'green' while diminishing net income reliance on oil assets proves a robust response to uncertainty in a 1.5C world



Decarbonization of Emission Leaders

Providing a financial case for the decarbonization of the Oil Majors helps stakeholders understand the potential these carbon emission leaders have to become net-zero vanguards

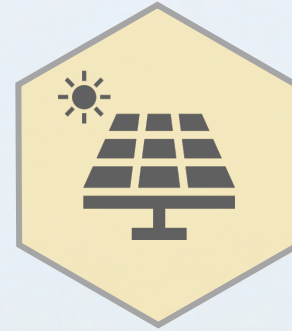


Future Work





Modeling
National
Oil Companies



Focus on corporate
governance
questions



Capital cost
sensitivity
analysis



Expanding
'green' asset
allocation



Mass rollout
as 1-player
game



Thank You!



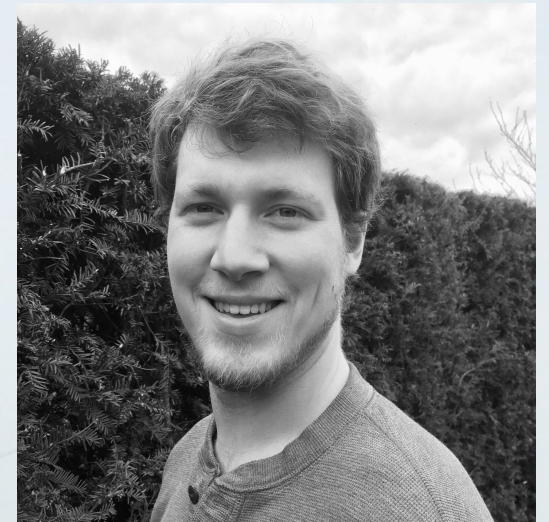
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