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Teaching through World Crisis Analysis: Quantifying Decarbonization in Transportation and Power

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Abstract

Decarbonizing the transportation and electricity generation sectors is critical for mitigating climate change, as these sectors collectively account for 53% of U.S. greenhouse gas emissions [1]. This paper evaluates the integration of a ”World Crisis Module” into a graduate-level ”Game Theory Applications in Engineering” course to examine the complex interplay between infrastructure transformation and stakeholder behavior. Utilizing an integrated pedagogical framework of discovery learning, challenge-based learning (CBL), and collaborative learning, students model the strategic interactions between three key players: the population, the transportation sector, and the electricity sector. Through collaborative workshops, students co-created research questions and modeled three distinct scenarios, including a full EV conversion by 2050 and the ”thermal transition” from natural gas to electric heating. Key quantitative findings include the discovery of a 7.8 million MW ”Peak Power Wall” and a monumental transfer of systemic risk to the electrical grid, as highlighted by the 2021 Texas power crisis. The results demonstrate that achieving a net-zero equilibrium is contingent on moving beyond siloed technical solutions to adopt coordinated, demand management. This study provides a transferable model for developing the systems-level literacy and strategic foresight required for engineers to architect a sustainable future.

Introduction

The accelerating global climate crisis, defined by the urgent need to achieve the Paris Agreement’s net-zero carbon goals, necessitates a fundamental shift in graduate engineering education [2]. Today’s students, the future leaders of tomorrow, will face a career defined by the worldwide response to global issues that are inherently interconnected. To prepare students for this reality, this paper describes the integration of a ”World Crisis Module” into a graduate-level engineering course. Specifically, this module was implemented within a ”Game Theory Applications in Engineering” course, providing a natural framework for students to model strategic interactions between competing stakeholders in a high-stakes environment. This pedagogical intervention is designed to move beyond traditional, siloed technical instruction by forcing students to engage with complex, multi-sector transformations through active analysis and discovery learning.

We intentionally selected a triad of active learning methodologies—challenge-based, discovery, and collaborative learning—as the educational architecture for this module, as each targets a specific cognitive barrier inherent in the decarbonization problem. Challenge-based learning

(CBL) was utilized to anchor calculations in a high-stakes ”world crisis” scenario, providing the emotional and professional urgency required to motivate students to move beyond single-variable optimization toward holistic systems analysis [16]. Discovery learning was selected because the physical constraints of the electrical grid (e.g., the ”Peak Power Wall”) are often counter-intuitive to students accustomed to seeing electricity as an infinite utility; by forcing students to ”discover” these limits through their own calculations, we ensure deeper belief and retention of the technical logic than a standard lecture could provide [12].

Finally, collaborative learning was implemented specifically to dismantle the misconception that society-wide issues can be solved within technical silos. The net-zero transition is fundamentally a multi-sector game where the optimal strategy for one player creates systemic failure for another. Collaborative learning in this context forces students to confront the reality that engineering solutions must exist at the intersection of conflicting priorities. Students learn that technical viability is only one component of a successful transition; the true challenge lies in a collaborative negotiation that balances the individual ”wants” and ”needs” of system users—such as cost-effectiveness and personal convenience—against the collective requirements of grid stability and the ”global good” of carbon reduction [19]. This pedagogical approach mirrors the professional interdependence required in real-world infrastructure planning, moving students from siloed technical solvers to collaborative strategic architects.

The implementation of discovery learning in this module is supported by a significant body of educational research highlighting its efficacy in STEM fields. Discovery learning, an inductive pedagogical approach, encourages students to draw on their past experiences and existing knowledge to discover facts and relationships [12]. Research by Prince and Felder demonstrates that inductive methods, including inquiry-based and problem-based learning, result in higher levels of student engagement and improved long-term retention of technical concepts compared to traditional deductive lectures [13]. In engineering specifically, discovery learning aligns with the need for ”self-directed inquiry,” which Bruner argues is essential for developing the structural understanding necessary to transfer knowledge to new, complex problems [14]. Furthermore, Wiggins and McTighe emphasize that ”meaning-making” through discovery allows students to move beyond the rote memorization of formulas toward an authentic understanding of systems-level interdependencies [15].

Complementing discovery learning, the module incorporates elements of Challenge-Based Learning (CBL), a framework that emphasizes learning through the resolution of large-scale, open-ended global challenges. Unlike traditional problem-based learning, CBL starts with a ”big idea”—in this case, global decarbonization—and requires students to define the specific technical questions and constraints themselves [16]. Malmqvist et al. demonstrate that CBL is particularly effective in engineering education because it fosters ”transdisciplinary” skills, requiring students to synthesize technical data with economic and social realities [17]. Furthermore, studies by Johnson and Brown indicate that CBL significantly enhances student motivation by providing a clear social purpose for technical analysis, thereby increasing the ”perceived value” of the engineering curriculum [18]. By framing the decarbonization of the U.S. grid as a competitive ”world crisis,” this module leverages the CBL framework to push students toward higher-order critical thinking and strategic foresight.

In addition to discovery and challenge-based frameworks, the module leverages collaborative learning to address the multidisciplinary nature of the energy transition. Collaborative learning, characterized by small-group interaction and positive social interdependence, has been shown to improve academic achievement and student persistence in engineering [19]. A meta-analysis by Springer et al. suggests that students who learn in small groups demonstrate higher levels of conceptual understanding and better problem-solving skills than those in competitive or individualistic environments [19]. Smith et al. argue that these "pedagogies of engagement" are vital for developing professional competencies such as communication and teamwork, which are critical when managing the conflicting objectives of diverse stakeholders [20]. By working collaboratively to solve the game-theoretic puzzles within the World Crisis Module, students simulate the professional dynamics of multi-agency climate task forces, learning that the most robust engineering solutions often emerge from cooperative negotiation and the synthesis of diverse perspectives.

The World Crisis Module is specifically designed to challenge students to explore a real-life worldwide threat, necessitating an exploration of the true complexity of the problem as well as the significant barriers to implementing effective solutions. By confronting these challenges in a structured academic environment, students learn that engineering solutions do not exist in a vacuum but are constrained by economic, social, and political realities.

The technical motivation for the module is the profound impact of the transportation and power sectors. In the United States in 2022, electric power and transportation accounted for 25% and 28% of greenhouse gas emissions, respectively—collectively 53% of the total [1]. Shifting transportation towards net-zero emissions can be achieved through the widespread adoption of electric vehicles (EVs), but that will in turn create additional demand for electricity. The module provides a framework to explore this transition by adopting a game-theoretic approach to model the strategic interactions between stakeholders: the population, the transportation sector, and the electricity sector. This educational framework allows students to analyze the complex interplay between individual choices, technological advancements, and policy interventions, providing them with the systems-level literacy required for a sustainable, low-carbon future.

Pedagogical Design and Implementation

The module is structured as a four-phase instructional cycle designed to break down technical silos and foster a collaborative mindset toward global issues. This structured design exceeds traditional in-class interactions by requiring students to actively co-create the investigative framework and negotiate the friction between user needs and the global good.

- **Phase 1: Problem Introduction and Net-Zero Targets:** Utilizing the CBL framework, students are presented with the "World Crisis" scenario: achieving net-zero greenhouse gas emissions by 2050. This phase provides the motivational anchor, establishing the specific carbon targets mandated by the Paris Agreement [2] and framing the decarbonization of the U.S. transportation and power sectors as a competitive, high-stakes engineering challenge.
- **Phase 2: Policy Investigation and Scope Definition:** In collaborative workshops, students investigate current policy mandates, such as the National Electric Vehicle Infrastructure (NEVI) program [9]. They brainstorm the scope of analysis, identifying potential friction points between stakeholder objectives. This phase concludes with students co-creating the

primary research questions, ensuring they define the technical and social constraints of the problem themselves.

- **Phase 3: Exploring Research Questions (Technical Discovery):** Students engage in discovery learning by performing quantitative analysis on raw data from the EIA and RECS. They calculate the baseline energy requirements for a 100% electrified fleet and the thermal transition of U.S. households. By calculating the results without pre-defined answers, students uncover the ”Peak Power Wall” and other physical grid constraints through their own inquiry.
- **Phase 4: Identification of Key Barriers and Policies:** The final phase utilizes collaborative learning to drive a structured discussion and identification of the key barriers and policies involved in a successful transition to net-zero emissions. Working together, students categorize the systemic barriers uncovered in previous phases—such as the infrastructure deadlock or capital asset inertia—and propose policy interventions (e.g., carbon pricing or AI-managed demand response). This phase requires a holistic view of the ”game,” forcing students to balance the individual wants of users with the requirements of the global good.

Key Research Questions

The module utilizes collaborative learning strategies to involve students in the co-creation of the investigative framework. Rather than receiving a static set of technical objectives, students participate in facilitated workshops where they brainstorm the primary friction points between aggressive policy targets and technical constraints. This collaborative process requires students to negotiate the scope of their analysis, ensuring that the investigative focus mirrors the real-world complexity of the decarbonization challenge. The following key research questions emerged as the direct result of this collaborative formulation process, representing the strategic nodes students identified as essential for a comprehensive system assessment:

- **I. Electric Vehicle Adoption and Impact:** What are the key factors (cost, range, infrastructure) influencing EV adoption? How do government incentives and consumer preferences for vehicle type (e.g., SUVs) affect overall electricity demand? What is the optimal mix of charging infrastructure needed to support widespread adoption?
- **II. Household Electricity Consumption Trends:** What are the primary drivers of consumption beyond EV charging? How do urbanization and changes in building efficiency standards influence demand? What is the pace of transition from fossil fuel-based heating to electric heat pumps?
- **III. Game Theoretic Framework:** How do strategic interactions between sectors influence the feasibility of net-zero? What policy interventions can shift the game’s equilibrium towards a net-zero outcome? Based on scenario analysis, is the 2050 target technically and economically feasible?

Stakeholder Interaction with Research Objectives

To effectively analyze the research questions, it is necessary to understand how each "player" in the game interacts with the stated objectives through their unique strategies and payoff functions. The characterizations of these interactions presented in this section were synthesized directly from collaborative classroom discussions, during which students simulated the strategic positioning of each stakeholder to define the primary friction points between their competing interests.

For Research Question I (EV Adoption), the Population is the primary decision-maker, whose strategy is dictated by a payoff of convenience and significant energy cost savings, often exceeding 50% relative to internal combustion engines. However, the Population's preference for larger vehicles (e.g., SUVs and light trucks) increases the average demand per unit to 0.34–0.55 kWh/mile. Simultaneously, the Transportation Sector influences this decision by choosing to expand infrastructure—specifically the "port explosion" required to reach 25–35 million ports—and investing in battery energy density, while the Electricity Sector must predict the resulting load to ensure grid stability and avoid the "Peak Power Wall."

For Research Question II (Household Trends), the Population's lifestyle choices and regional dependencies—such as the Northeast's reliance on heating oil or the Midwest's 65% natural gas penetration—directly drive the baseline demand. The transition to electric heat pumps represents a strategic shift for the population that transfers demand from the natural gas sector to the power sector. While this reduces the Population's annual energy bill, it creates a "Risk Transfer" for the Electricity Sector, which must manage extreme weather surges, as demonstrated by the 2021 Texas power crisis where electric resistance heating tripled instantaneous demand.

Finally, for Research Question III (Policy and Feasibility), the interactions reach a systemic level. The Transportation Sector and Electricity Sector compete for material resources and grid priority. Achieving the 2050 target is contingent on finding a game equilibrium where all three players' strategies align. Policy "game levers," such as the NEVI program or carbon pricing, are analyzed for their ability to break the "fossil inertia" of an aging 283 million-vehicle fleet (average age 13 years) and shift the strategic landscape toward a net-zero outcome.

A Game Theoretic Framework

We model the interaction between the population, transportation, and electricity sectors as a non-cooperative game, formulated through classroom synthesis of current market and grid data.

Players and Strategic Motivations:

- **Population (P):** The strategic motivation for the Population player is centered on the dual priorities of cost and convenience. Individual decision-making regarding vehicle adoption and home energy usage is driven by the desire to minimize upfront capital expenditures and ongoing operational costs while maintaining the high standard of convenience afforded by current technologies. In the context of the game, this player will only transition to net-zero technologies if the economic payoff—such as the identified 50%+ reduction in annual fueling costs—outweighs the perceived inconvenience of charging times and infrastructure gaps.

- **Transportation Sector (T):** This sector is primarily motivated by the challenge of managing societal benefit against strict budgetary constraints. Manufacturers and infrastructure planners must optimize the deployment of zero-emission technologies, such as the scaling of charging ports to 25–35 million by 2050, within the limits of public program budgets (e.g., NEVI) and private investment thresholds. Their payoff is achieved when they provide maximum public utility and transition progress while remaining within these rigorous fiscal boundaries.
- **Electricity Sector (E):** The primary strategic focus for the Electricity Sector player is maintaining service. Grid reliability and continuity are the paramount payoffs; the sector must balance the massive load surges from the ”Peak Power Wall” and the ”thermal transition” against the intermittent nature of renewable generation. Success is defined by the absolute avoidance of outages and the continuous delivery of service to all consumers, even under the systemic strain of deep electrification.

Payoff Interdependencies:

Each player’s optimal strategy is constrained by the actions of others, creating a complex interdependent payoff matrix. The Population’s cost-driven strategy of adopting heavy SUVs (0.55 kWh/mile) maximizes individual utility but threatens the Electricity Sector’s payoff by heightening the risk of service failure at the ”Peak Power Wall.” Conversely, the Electricity Sector’s strategy of implementing time-of-use (TOU) tariffs directly modifies the Population’s cost-saving payoff to incentivize grid-favorable behavior. The Transportation Sector acts as the critical intermediary; its failure to provide adequate infrastructure within its strict budgets would result in a ”losing state” where the Population retreats to aging ICE vehicles, causing all sectors to miss 2050 decarbonization targets.

Strategic Friction and Equilibrium Barriers:

The game is currently characterized by a ”non-cooperative” state where individual actors maximize utility without system-level coordination. Through discovery modeling, students identified four primary barriers that prevent the game from reaching a stable Net-Zero Equilibrium, each with severe implications for the feasibility of proposed solutions:

- **The Infrastructure Deployment Barrier:** A massive misalignment exists between the Transportation Sector’s current capital trajectory and the required 25–35 million charging ports. Within strict budget constraints, the sector cannot deploy infrastructure ahead of demand, yet the Population will not adopt EVs without ubiquitous ports (a classic ”Deadlock” state). This barrier implies that purely market-driven adoption is unfeasible; deep public subsidy is the only strategic lever to break the deadlock.
- **The Peak Load Capacity Barrier:** The identified ”Peak Power Wall” of up to 7.8 million MW creates a physical constraint. A non-cooperative strategy where the Population charges ”at-will” (convenience maximization) is technically incompatible with the Electricity

Sector's requirement to maintain service. This implies that "Dumb Charging" makes a Net-Zero grid physically impossible, regardless of how much renewable energy is generated.

- **The Resilience and Thermal Transfer Barrier:** The "Thermal Transition" shifts energy security from distributed natural gas storage to a single point of failure: the electric grid. As seen in the 2021 Texas Power Crisis, extreme weather can shift the game into a "systemic collapse" state. This implies that the feasibility of net-zero is contingent on the Electricity Sector over-investing in firm, carbon-free baseload (e.g., Nuclear or CCS), which directly conflicts with the Population's desire for low energy costs.
- **The Capital Inertia Barrier:** The slow turnover rate of the U.S. fleet (average age 13 years) and home heating systems (20–30 year lifespan) creates a "Time Lag" friction. Even if current technology is superior, the game is "locked" into fossil fuel strategies by past investments. This implies that reaching 2050 targets is unfeasible without policy levers that force the premature retirement of fossil-fuel assets.

Students concluded that feasibility is not a technical question of "can we build it," but a strategic question of whether these four barriers can be navigated through cooperative "game rules" like AI-managed demand response and mandatory building electrification codes.

Current State of the Game: Analysis of Trends

To assess the feasibility of the 2050 goals, the module requires students to analyze the current empirical "state of the game." This involves a data-driven review of the trends underlying the key research questions.

- **Trends in EV Adoption and Impact:** Entering 2026, the global EV stock has surpassed 60 million vehicles, yet the market has transitioned from a phase of exponential growth to one of moderated expansion [3]. In the United States, while annual sales remained above 1.5 million through 2025, the growth rate has significantly cooled. This deceleration is largely attributed to "early adopter exhaustion" and high interest rates. EVs still account for less than 8% of the total U.S. light-duty fleet. Inertia remains high; the average vehicle age is nearly 13 years [4]. Furthermore, the "strategy" of financial incentives has shifted; the 2024/2025 implementation of stricter sourcing rules reduced the number of models eligible for federal tax credits. This retreat by policymakers has increased the upfront cost for the population, leading several major manufacturers to pivot toward plug-in hybrids (PHEVs) as a medium-term hedge.
- **Trends in Household Consumption:** Baseline electricity consumption is currently evolving due to a "thermal transition" and rising per capita demand. On average, a U.S. household consumes between 30 and 33 kilowatt-hours (kWh) of electricity per day, equating to an hourly average of 1.25 to 1.38 kWh [5]. Currently, natural gas remains the dominant fuel for space heating and cooking in the United States, used in approximately 50% of households [6]. Residential natural gas prices currently average between $1.40 and $1.80 per hundred cubic feet (ccf), with prices projected to rise by 1-2% annually [7]. Residential electricity costs in the U.S. currently average between $0.17 and $0.19 per

kWh, resulting in an average monthly electric bill ranging from approximately $135 to $165. Projections indicate a sustained growth in these costs, with EIA forecasts suggesting a 2-3% annual increase in real terms as utilities pass through the capital expenditures associated with decarbonization and grid hardening [5].

- **Trends in Policy and Grid Capacity:** As of early 2026, the U.S. has approximately 1.35 million MW of generation capacity. The current breakdown reveals a heavy dependence on fossil fuels: natural gas remains the dominant source at 43.9%, followed by coal at 16%. Total annual electricity usage in the United States currently stands at approximately 4,000 Terawatt-hours (TWh) [5]. Projections from the EIA's Annual Energy Outlook (AEO) indicate that this usage will grow to between 5,500 and 6,000 TWh by 2050 as the electrification of transportation and buildings accelerates [7]. The EIA projects that renewable energy generation—specifically solar and wind—will grow across all cases, driven by declining costs and federal tax credits. To achieve net-zero, the 2050 generation capacity is projected to reach over 2.5 million MW. In the EIA's reference cases, zero-carbon generation increases to provide nearly 44% to 59% of total electricity by 2050. Solar alone is projected to exceed 1 million MW, while energy storage is projected to scale to over 400,000 MW. However, the EIA also notes that natural gas capacity is expected to remain a significant "strategic" component of the mix to provide reliable peaking power, maintaining over 300,000 MW of capacity in many 2050 scenarios to manage the intermittency of the 60-70% renewable share [7].

The Role of Electric Vehicles

The transition to electric vehicles (EVs) represents the most significant shift in the strategic interaction between the Population and the Transportation sector. To quantify this transition, students must analyze the technical parameters of the current and future fleet. *Efficiency and Range:* Current EV efficiency typically ranges from 0.25 to 2.5 kWh/mile, with a significant breakdown by vehicle type [8]:

- **Passenger Sedans:** 0.25–0.30 kWh/mile (e.g., Tesla Model 3, Hyundai Ioniq 6).
- **Light SUVs and Crossovers:** 0.30–0.38 kWh/mile.
- **Large SUVs and Light Trucks:** 0.45–0.55 kWh/mile (e.g., Ford F-150 Lightning, Rivian R1S).
- **Heavy-Duty Semi-Trucks (Class 8):** 1.7–2.5 kWh/mile (e.g., Tesla Semi, Freightliner eCascadia).

Range trends have seen a significant upward trajectory, with the average range for new EVs surpassing 270 miles in 2025, up from just 150 miles a decade prior [3]. *Charging Infrastructure:* Current U.S. estimates show approximately 190,000 total public charging ports [8]:

- **Level 1 (Standard Outlet):** 1.4 kW output. Suitable for home installation; ubiquitously available in households (120V).
- **Level 2 (Home/Public):** 7.2 kW to 19.2 kW output. The standard for home installation (240V). Comprises 140,000 public ports.

- **DC Fast Charging (Highway):** 50 kW to 350 kW output. Essential for long-distance travel; 48,000 public ports. Not suitable for residential installation.
- **Megawatt Charging System (MCS):** 1,000 kW to 3,750 kW output. Designed for commercial heavy-duty vehicles.

Planned Increases: The NEVI program targets 500,000 public ports by 2030, while 2050 projections suggest a requirement of 25–35 million workplace and public ports [9]. *Projected Annual Demand:* Based on 3.2 trillion annual VMT [10], a full electric conversion would require 800 to 1,200 TWh of additional electricity per year. The estimated composition of the projected 2050 U.S. fleet is detailed in Table I.

Table 1: Projected U.S. Vehicle Fleet Composition

Vehicle Type	Current (M)	% of Total	2050 Est. (M)
Passenger Cars	104.2	36.8%	130.3
Light Trucks (SUVs/Pickups)	158.5	55.9%	198.1
Medium/Heavy Trucks	11.3	4.0%	14.1
Motorcycles	9.4	3.3%	11.8
Total	**283.4**	**100%**	**354.3**

Comparative Annual Energy Costs: Analysis reveals significant operational savings for the Population player. A comparison of these costs across vehicle types is provided in Table II.

Table 2: Comparative Annual Energy Costs (12k miles/yr)

Vehicle Type	ICE Efficiency	EV Efficiency	ICE Annual Cost	EV Annual Cost
Passenger Sedan	32 MPG	0.28 kWh/mi	$1,238	$605
Light SUV/Crossover	24 MPG	0.34 kWh/mi	$1,650	$734
Large SUV/Truck	18 MPG	0.48 kWh/mi	$2,200	$1,037
Semi-Truck (100k mi)	6.5 MPG	2.0 kWh/mi	$58,462	$36,000

Household Electricity Use Trends

Regional Analysis of Household Energy Use: The ”payoff” for the Population player is heavily influenced by geography. In the graduate course, students analyze RECS data to understand regional dependencies on energy sources [6]. The distribution is summarized in Table III.

Case Study: The 2021 Texas Power Crisis: Utilizing Winter Storm Uri, students analyze how extreme cold tripled demand due to electric resistance heating. This crisis illustrates the ”losing state” in game theory where generation fails despite soaring demand, highlighting the need for winterization and strategic peaking capacity [11].

Table 3: Regional Analysis of Household Energy Use

Region	Primary Source	Secondary Source	Regional Trend
Northeast	Natural Gas (55%)	Heating Oil (25%)	Highest fuel delivery dependence.
Midwest	Natural Gas (65%)	Electricity (25%)	High winter peak shift risk.
South	Electricity (60%)	Natural Gas (35%)	Compounding AC and EV loads.
West	Electricity (45%)	Natural Gas (45%)	Balanced but varied infrastructure.

Scenario Analysis

We analyze three scenarios to assess feasibility, forcing students to reconcile the ”State of the Game” trends with Net-Zero goals:

Scenario 1: Full EV Conversion and The Peak Power Wall. This scenario models the 100% transition of the projected 2050 U.S. fleet of 354.3 million vehicles (see Table I). Students perform a ”discovery” calculation to quantify the instantaneous load on the grid. If the fleet charges simultaneously at Level 2 (7.2–19.2 kW), the load ranges from 2.4 to 7.8 million MW. Students must contrast this with the 2050 capacity projection of 2.5 million MW, leading to the conclusion that a ”dumb” charging strategy is technically impossible.

Scenario 2: The Thermal Transition and Regional Vulnerability. Building on the regional energy analysis summarized in Table III [6], this scenario focuses on shifting households currently using natural gas to electric heating. Students calculate the surge in winter peak demand, particularly in the Midwest. Using the 2021 Texas Power Crisis [11] as a benchmark, they model a weather event where heat pump efficiency drops and resistance heating takes over.

Scenario 3: Policy Trajectories and the Emissions Gap. Students compare current ”business-as-usual” renewable deployment rates and the cooling EV adoption trends against the targets required by the Paris Agreement [2]. They utilize the EIA’s Annual Energy Outlook cases—where zero-carbon generation only reaches 44–59% [7]—to quantify the ”Emissions Gap.”

Results and Discussion

The synthesis of state-of-the-game trends and scenario outcomes reveals a fundamental strategic conflict between the goals of the three primary players. The following analysis explores the implications of each scenario through the game-theoretic lens,highlighting how the pedagogical approaches defined in the instructional cycle facilitated these insights:

Scenario 1: The Infrastructure-Demand Paradox: The discovery of the ”Peak Power Wall” (7.8 million MW) implies that a non-cooperative game equilibrium is physically unsustainable. This finding was the direct result of discovery learning (Phase 3), where students performed calculations on raw data to find that the Electricity Sector cannot simply build its way out of the problem. Instead, the strategy must pivot to demand-side flexibility. For the Population, this means a shift where ”convenience” must be traded for ”cost” (off-peak rates). This necessitates massive deployment of smart-charging and V2G hardware. Furthermore, the 2.4 million MW lower bound represents a nearly 100% increase over current total generation capacity, suggesting that the grid's distribution level (local transformers) will be the most critical bottleneck.

Scenario 2: Risk Transfer and the Reliability Premium: The transition from natural gas to electric heating represents a massive transfer of systemic risk. The CBL framework (Phase 1) provided the necessary context to understand that a Net-Zero grid must be ”over-engineered” for resilience, an implication underscored by the 2021 Texas Power Crisis. The Electricity Sector player faces a choice: rely on intermittent renewables or maintain ”firm” baseload capacity. The EIA's 2050 projections suggest a strategic role for natural gas, but for a Net-Zero outcome, this must be paired with Carbon Capture and Storage (CCS). For students, identifying this ”reliability premium” became a dominant factor in determining the feasibility of future utility rates.

Scenario 3: The Inertia of the Fossil Equilibrium: The current policy trajectory highlights the ”Emissions Gap.” Through collaborative learning (Phase 4), students discovered that market forces are insufficient to dislodge the existing ”carbon lock-in” of natural gas and ICE fleets. The average vehicle age of 13 years creates massive systemic inertia. To reach the 2050 target, students concluded that policy ”game levers” must move beyond simple subsidies to more aggressive interventions, such as building mandates or carbon pricing, to prematurely retire fossil-fuel assets.

Conclusion

Achieving net-zero GHG emissions in the transportation and electricity sectors by 2050 is technically feasible but historically unprecedented in scale. The feasibility analysis conducted through the World Crisis Module reveals that while individual Population players are highly incentivized by cost savings exceeding 50% (as shown in Table II), the resulting collective strategy creates a ”Peak Power Wall” of up to 7.8 million MW. The pedagogical integration of challenge-based learning (CBL), discovery learning, and collaborative learning proved essential for students to navigate this complexity. The CBL framework (Phase 1) provided the motivational urgency required to explore non-obvious engineering solutions, such as automated load-shifting and the necessity of firm baseload power. By utilizing discovery learning (Phase 3), students ”found” the physical limits of the grid themselves, resulting in a deeper retention of technical constraints.

Furthermore, the implementation of collaborative learning (Phases 2 and 4) mirrored the professional dynamics of modern infrastructure planning. By co-creating research questions and negotiating strategic barriers, students moved beyond siloed technical analysis to an authentic understanding of systems-level interdependencies. Collaborative synthesis of the 2021 Texas Power Crisis and regional energy dependencies (see Table III) allowed students to identify the monumental ”Risk Transfer” inherent in the thermal transition, concluding that grid resilience is inseparable from climate survival. This module demonstrates that the 2050 target is ultimately infrastructure-bound, requiring a strategic shift for the Transportation Sector from incremental port deployment to the rapid scaling of over 25 million ports.

In conclusion, the integration of these active learning methodologies prepares graduate engineers for the transdisciplinary challenges of the energy transition. By confronting the strategic friction between individual convenience and systemic service maintenance, students develop the systems-level literacy and strategic foresight needed to successfully architect a sustainable future that balances individual wants against the global good. The World Crisis Module provides a transferable model for engineering education, proving that when technical analysis is grounded in collaborative, challenge-driven inquiry, students are better equipped to define and solve the complex multi-sector problems of the 21st century.

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