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Case Study in Techno-Economic Analysis: Using Electric and Gasoline Vehicles to Teach Technical and Financial Constraints

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Abstract

Engineering students learn to use technical requirements and constraints to make decisions in the majority of their coursework. However, practicing engineers are often profoundly affected by financial constraints, which can significantly influence decision-making and constrain design options. Engineering economics courses are often the only opportunities for engineering students to combine the technical and economic aspects of engineering and develop the skills for more comprehensive decision-making.

This paper presents a techno-economic case study that uses the technical and financial aspects of electric and gasoline vehicles to help students explore how both will influence decisions and how they are inextricably intertwined.

Students are tasked with developing a "first-cut" net present value analysis comparing the one-time capital, recurring operating, and end-of-life cash flows for electric and gasoline vehicles to determine the better option. Since students are developing the analyses and making assumptions, the results vary widely, and there is rarely a clear answer.

The case study analysis demonstrates that finances are a critical constraint in engineering design. It also highlights the uncertainty and variability in design decision-making, as well as the assumptions that feed the entire process. The most important takeaway is the realization that technical metrics largely determine the financial outcome, and vice versa.

Introduction and Background

In a perfect world, an engineer could make design decisions without concern for the cost. Everything would be optimized and closer to ideal. Nothing would be sacrificed, and the only limits would be physics. Unfortunately, that world does not exist, and engineering students do not appear to realize it in a meaningful way.

Engineering Economics courses and their textbooks generally present a comprehensive view of engineering-economic decision-making, beginning with fundamental concepts, including how to estimate costs and benefits and how accounting information supports economic analysis. They progress through core evaluation tools (i.e, present worth, annual worth, rate of return), while also addressing risk, uncertainty, and the influence of future events on financial outcomes. Additional major topics include depreciation, corporate taxes, economic life and replacement analysis, and the effects of inflation and price changes on engineering decisions [1, 2]. The intentional combination of technical and economic factors in the Techno-Economic Analysis (TEA) methodology is an opportune way for engineering students to go beyond financial analyses to explore the tension between technical and monetary constraints, two often conflicting values.

Rather than presenting a singular classroom exercise, this paper advocates for the use of techno-economic case studies as a general instructional method for integrating technical analysis, economic reasoning, and professional judgment in engineering education.

In the sections that follow, there will be a brief background on TEA and the case-study scenario. Then, the paper presents an example analysis and results. Finally, there will be a concluding discussion.

Techno-Economic Analysis

In engineering decision-making, technical requirements and constraints (such as performance specifications/targets, safety standards, material limitations, or system architecture) must increasingly be balanced against financial considerations, as cost optimization, budget limits, and lifecycle economics drive real-world project viability. Because every technical choice directly affects cost, feasibility, and long-term economic outcomes, the industry must continually integrate rigorous technical analysis with careful economic evaluation to ensure designs remain both functionally sound and financially sustainable. This ongoing interplay makes engineering design a process of negotiating what is technically possible within the boundaries of what is economically practical.

TEA is a method for evaluating the economic performance and overall value of a technology by weighing its benefits against its costs. It often involves benchmarking, in which a new technology's costs are compared directly with those of existing commercial alternatives. This comparison helps determine whether the latest technology can be competitive in real-world markets. Because cost-competitiveness is essential for commercialization, TEA aims to assess whether a technology can achieve cost parity while still offering technical advantages. Even when a technology is at a low readiness level, TEA assumes full industrial-scale deployment to estimate realistic long-term costs [3]. The key components of TEA (technical assessment, economic analysis, and financial modeling) [4] are precisely the skills students can develop in an engineering economics course, so using case studies to practice the methodology has proven invaluable.

The purpose of this paper is to present one such case study. In this example, students compare the technical and economic aspects of purchasing an electric or gasoline vehicle. This paper presents the elements of a course module that instructors can use to help engineering students practice TEA and the technical and financial analysis skills required therein. The focus here is not on measuring student understanding, but rather a structured set of resources that an instructor could implement in their course as a case study in TEA.

Scenario Description

The techno-economic case study presented here asks students to compare electric vehicles (EVs) and gasoline vehicles (GVs) by developing a "first-cut" net present value (NPV) analysis of both. Learning occurs because students must make assumptions (incorporating uncertainty and ambiguity) about the relevant technical parameters of a vehicle's performance and the financial parameters of cost of ownership. EVs seem like an obvious choice given their sustainability benefits and lower operating costs, but comparable vehicles do carry a premium. The analysis requires engineering students to better understand the technical performance and financial costs of EV and GV ownership.

NPV is a decision-making tool that evaluates whether a project or investment will create value by converting all expected future cash flows to present-day equivalents and comparing them with the initial cost. It is widely used because it incorporates the time value of money, enabling decision-makers to objectively compare alternatives and choose the option that delivers the most significant economic benefit. Its key components (interest rate, service life, and cash flows) work together to determine how future benefits and costs translate into today's dollars, making NPV one of the most reliable methods for guiding engineering and financial decisions. In this work, interest rate is used as an umbrella term for the rate at which equivalence calculations are executed.

Students are encouraged to research values for service life, miles driven, energy costs (fuel or electricity), maintenance, salvage value, and many others (discussed in detail below). Some expenses have technical drivers, while some do not. Each student makes their own assumptions, so they practice living with uncertainty and ambiguity. Ultimately, the results vary widely. As a reminder, this paper does not present a TEA of the EV versus GV. Instead, it presents a pedagogical case study that prioritizes student learning over precise analysis and accurate results.

Example TEA

To fully describe the case study, this paper presents a TEA below for the EV-versus-GV case. The analysis and results presented here are more comprehensive than those of the average undergraduate engineering student, but they could serve as a sort of 'example solution' to the assignment. In this example, the TEA will be an NPV analysis.

It is worth noting that this is also an example of the appropriate and realistic use of Artificial Intelligence (AI) in the classroom. AI can do this analysis, but asking students to use AI as a research tool instead of an analysis tool helps them use modern technology and develop the skills we know they need. A deeper discussion of the use of AI in this context is included in the Conclusion below.

Analysis Methods

The first step in completing the analysis is to determine what cash flows to include. A summary of the parameters is presented in Table 1 below. It is worth noting that this analysis does not include the cost to finance the vehicle (assuming an upfront cash payment). It also does not account for any depreciation-based tax savings, instead only including an end-of-life salvage value.

The second step is to determine which EV and GV to compare for the TEA. This example begins with the most popular EV in Oregon (and the United States), the Tesla Model Y [5]. To pick a GV, MS Copilot suggested comparable gas vehicles, including the 2025 Toyota RAV4 Limited AWD, which has features similar to the 2025 Tesla Model Y Long Range AWD.

Table 1: Summary of Parameters and Values used in TEA

Parameter	Recurrance	Vehicle	Toyota (GV)	Tesla (EV)	Units
purchase price	one-time	Both	-38,950.00	-48,990.00	[$]
maintenance & repairs	annual	Both	-603.32	-614.85	[$]
insurance	annual	Both	-1,475.00	-2,000	[$]
title	one-time	Both	-106.00	-192.00	[$]
registration	biennial	Both	-136.00	-316.00	[$]
home charger	one-time	EV	-	-1,199.00	[$]
battery replacement	one-time	EV	-	see text	[$]
rebates	one-time	EV		10,000	[$]
salvage	one-time	Both	18,000	12,500	[$]
mileage	annual	Both	11,000	11,000	[miles]
efficiency	-	GV	28	-	[miles/gal]
efficiency	-	EV	-	3.75	[miles/kWh]
fuel	-	GV	4.23	-	[$/gal]
electricity	-	EV	-	0.09	[$/kWh]
energy costs	annual		-1,661.79	-266.35	[$]

The third step is to determine each parameter value. This step requires the most time and effort for the students, and is filled with assumptions and nuances. The ambiguity in this part of the process presents learning opportunities, which will be highlighted in the Discussion section below. Here, each parameter is presented with a brief description.

- The purchase price varies widely as many factors influence it, and it was estimated based on each vehicle's MSRP. It was estimated at $38,950 for the Toyota [6] and $48,990 for the Tesla [7].
- Maintenance and repairs are a widely variable parameter, so MS Copilot estimated the costs for each vehicle. The output was an estimate based on recurring service tasks, manufacturer recommendations, and known EV vs. GV maintenance patterns. As an interesting point, the estimate included that all Toyota vehicles come with ToyotaCare, which covers the first two years of vehicle maintenance [8].
- Insurance is also a widely variable parameter, so MS Copilot estimated the costs for each vehicle. The output was an estimate based on nationally reported insurance averages for each model, then adjusted to reflect Oregon's generally moderate insurance rates.
- In the State of Oregon, there are different title and registration fees for GVs (based on miles/gal) and a flat (higher) fee for EVs. The title fee applies only to the purchase of the vehicle, while registration is required every two years [9].
- In this example, assume that a Level 2 home charger will be installed to charge the Tesla in a reasonable time. The cost is estimated based on my own home installation.
- The battery replacement is an example of the adaptability required in one of these analyses. Partway through the analysis, the research suggested excluding the cost of battery replacement because modern EVs do not need battery replacements as often as they used to. Depending on use, these batteries can last upwards of 15 years [10], which is longer than our service life.
- EVs do come with some rebates, though the United States and the State of Oregon are phasing them out. The analysis includes a $7,500 federal rebate [11] and the $2,500 Oregon rebate [12] for a total of $10,000.
- MS Copilot estimated salvage value given the wide variability in data. The result was an estimate based on my service life of 9 years and aggregated data from many vehicle resale websites using an estimated depreciation schedule.

The six values below the bold line in Table 1 require some extra explanation. First, we must assume that both cars drive the same mileage each year, which, in our analysis, is 11,000 [13]. Then we must research the efficiency of the specific vehicles (28 miles/gal for the Toyota and 3.75 miles/kWh for the Tesla) [14, 15]. The costs of gasoline and electricity are location-dependent and highly variable. For this example, values from my local gas station and my electricity bill are used. The energy costs calculation is shown below as Equation 1. The analysis did not consider public charging options.

$$\text{energy costs} = \text{mileage} * \frac{\text{fuel (or electricity) cost}}{\text{efficiency}} \quad [1]$$

The interest rate used in the NPV analysis can be challenging to define, so it is recommended to have students pick a reasonable value and use it as a variable to see how it affects the result. In this example, the analysis assumes a 10% interest rate. The service life was estimated at 9 years [16, 17], which corresponds to the estimated average number of years Americans keep their new vehicles.

Once all parameters are estimated, the NPV analysis is performed in MS Excel.

- The cash in is determined as any positive cash flows in any given year. In our example, the rebates for the EV (in Year 0) and the salvage values for both vehicles (in Year 9).
- The cash out is the same for both EVs and GVs, but does vary by year. In Year 0, it consists of the purchase price, title, and the first registration fee. In Years 1, 3, 5, 7, and 9, it consists of energy costs, maintenance/repairs, and insurance. In Years 2, 4, 6, 8, and 10, it includes energy costs, maintenance/repairs, insurance, and biennial registration fees.
- The rest of the calculations are given in Equations 2, 3, and 4 [2]. In these equations, i is the interest rate, n is the year index, PV is the present value, and N is the total number of years.

$$\text{net cash} = \text{cash in} + \text{cash out} \quad [2]$$

$$\text{PV}_n = \text{net cash}_n * (1 + \text{i})^{-n} \quad [3]$$

$$\text{NPV} = \sum_{\text{n}=0}^{\text{N}} \text{PV}_\text{n} \quad [4]$$

Results

For this example, with the parameters and values presented above in Table 1, the TEA NPVs for the GV and EV are shown in Figure 1a and 1b, respectively. The net cash flow diagram is shown in Figure 2. In this example, with these parameter values, the two options are nearly identical. The EV performs slightly better in NPV/TEA, indicating it is the better choice. It is worth noting that, since both are negative, one could choose 'no project' as a viable alternative, implying that purchasing a vehicle will not pay off because it generates no revenue.

a) GV: 2025 Toyota RAV4 Limited AWD					
Year	Cash In	Cash Out	Net Cash	PV	NPV
0	$ -	$ (39,192)	$ (39,192)	$ (39,192)	$ (53,443)
1	$ -	$ (3,740)	$ (3,740)	$ (3,400)	
2	$ -	$ (3,876)	$ (3,876)	$ (3,203)	
3	$ -	$ (3,740)	$ (3,740)	$ (2,810)	
4	$ -	$ (3,876)	$ (3,876)	$ (2,647)	
5	$ -	$ (3,740)	$ (3,740)	$ (2,322)	
6	$ -	$ (3,876)	$ (3,876)	$ (2,188)	
7	$ -	$ (3,740)	$ (3,740)	$ (1,919)	
8	$ -	$ (3,876)	$ (3,876)	$ (1,808)	
9	$ 18,000	$ (3,740)	$ 14,260	$ 6,048	

b) EV: 2025 Tesla Model Y Long Range AWD					
Year	Cash In	Cash Out	Net Cash	PV	NPV
0	$ 10,000	$ (50,697)	$ (40,697)	$ (40,697)	$ (52,791)
1	$ -	$ (2,881)	$ (2,881)	$ (2,619)	
2	$ -	$ (3,197)	$ (3,197)	$ (2,642)	
3	$ -	$ (2,881)	$ (2,881)	$ (2,165)	
4	$ -	$ (3,197)	$ (3,197)	$ (2,184)	
5	$ -	$ (2,881)	$ (2,881)	$ (1,789)	
6	$ -	$ (3,197)	$ (3,197)	$ (1,805)	
7	$ -	$ (2,881)	$ (2,881)	$ (1,479)	
8	$ -	$ (3,197)	$ (3,197)	$ (1,492)	
9	$ 12,500	$ (2,881)	$ 9,619	$ 4,079	

Figure 1: NPV Calculations and Results for a) GV-Toyota and b) EV-Tesla

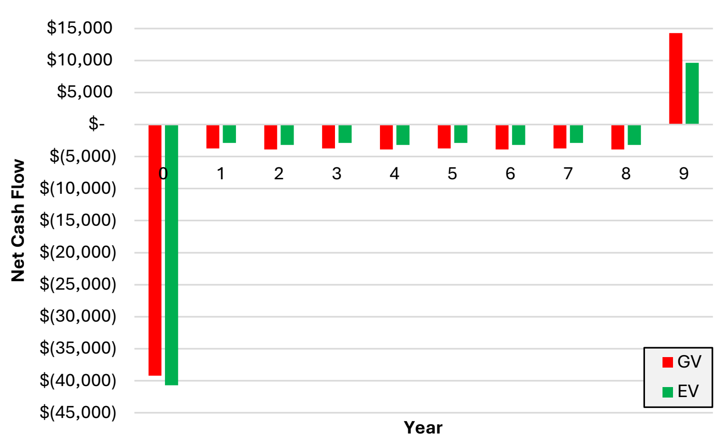

Figure 2: Cash Flow Diagram for the NPV TEA of GV and EV

This case study presents many opportunities to modify the parameters and gain insight into how each parameter influences the analysis outcome. To illustrate the point, the example analysis can be repeated for a variable interest rate (from 0% to 35%) and for the case of no EV rebate. This modified analysis is shown in Figure 3, which presents the same data with two different y-axis scales (Figures 3a and 3b). In Figure 3a, notice that the interest rate doesn't change the analysis outcome, so it is not as critical a factor as might be assumed. Figure 3a also shows that the EV and GV have very similar NPVs at all interest rates.

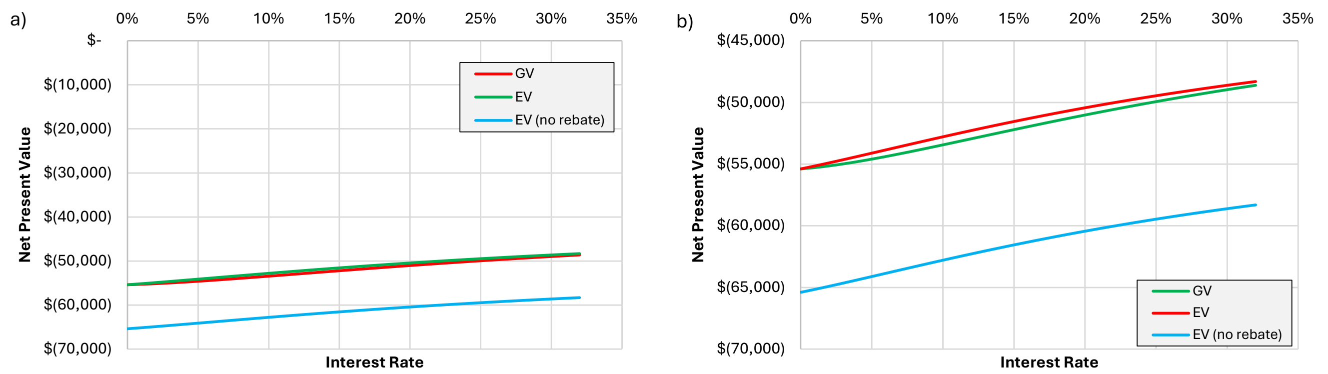

Figure 3: NPV for GV, EV, and EV without rebate at various interest rates

By performing the analysis without the rebate, we see a significant difference in NPV and conclude that the EV is a much less attractive option in the marketplace without it. In fact, rebates like this are one tool policy-makers use to influence the marketplace and can increase the adoption rate of innovative technologies.

The analyses with and without the rebate are good examples of how this case-study method can be used to improve engineering students' preparation in areas beyond the technical. It creates opportunities to discuss variability, ambiguity, and, most importantly, the "why?" behind some of our assumptions and decisions.

Discussion of Variability and Learning Opportunities

When analyzing the financial scenarios in this case study, there will be variability in outcomes. The results will naturally differ because each student may make slightly different yet reasonable assumptions throughout the process. These assumptions directly influence the NPV calculations. Small changes in some parameters can significantly shift the outcome, while significant changes in others can have almost no impact. This variability is intentional, as it illustrates the uncertainty inherent in real-world decision-making, where engineers often must choose a path despite incomplete information and competing estimates. Rather than searching for a single "correct" answer, students should recognize the complexity of their technical and financial models and focus on justifying their assumptions, interpreting how those assumptions shape their results, and understanding why multiple valid solutions can emerge from the same problem.

Every decision made in the analysis is inherently an opportunity for students to explore this real-world, applied exercise. Some initial discussion points are included below.

- The vehicle choice decision requires some discernment. It may make sense to pick two vehicles that are similar in price, but in reality, students should explore concepts about market segmentation and pricing. Two identical cars (one being gasoline and one being electric) will not have the same price, because market forces currently place a premium on EVs. For example, two 2025 Hyundai Kona Limited models (one gasoline and one electric) differ by $7,550 (higher for the EV) [18].

- The purchase price variability depends on many factors, and encourages students to consider supply/demand and variations in customer preference. For example, All Wheel Drive increases vehicle cost, and EV features like extended range will increase cost but reduce efficiency (more battery weight means lower miles/kWh). Also, some high-demand cars will require additional fees for transportation or securing ownership.
- The mileage parameter can vary based on user demographics and geography. For example, vehicles used in rural or suburban communities will have more annual mileage than vehicles used in urban areas with high walkability, bikeability, and public/mass transit. Also, larger households tend to drive more, as there may be multiple drivers or children who need to be transported by their parents.
- The efficiency parameter can vary based on vehicle choice and features. Different vehicle trims have different efficiencies because each additional feature may use energy. For example, cars with heated seats or All-Wheel Drive use more energy, so their overall vehicle efficiency will differ. Similarly, long-range EVs are heavier (because of additional batteries) and consequently have lower efficiency.
- The cost of fuel varies significantly due to geographic, technological, political, and market factors. Gasoline prices vary considerably across regions due to differences in geography, refining capacity, and fuel production technologies. These differences, combined with political policies and changing global market conditions, create a complex system in which gasoline prices are constantly in flux. Similarly, students can explore the significance of the GVs that recommend or require higher-octane fuel, which is more expensive.
- The cost of electricity varies significantly due to geographic, technological, regulatory, temporal, and market factors. The cost of electricity varies widely because it depends on geographic differences in energy supply, technological aspects such as generation methods, and regulatory structures that dictate pricing. Time-of-use systems (where off-peak, mid-peak, and on-peak rates differ) further influence costs, along with the higher price often associated with renewable energy, which can require additional infrastructure or integration expenses. Customers also pay for transmission and distribution, meaning the physical delivery of electricity adds another layer of variability to final consumer pricing. One could also consider that public charging options charge different rates for electricity.
- In considering maintenance and repairs, students can consider that gasoline vehicles require different maintenance than electric vehicles (e.g., EVs do not need oil changes, spark plugs, or exhaust system maintenance). Similarly, EVs may need battery replacement (at a high cost), but most people don't keep their cars long enough to warrant it.
- In considering insurance, students can consider that EVs might have higher costs due to expensive parts, advanced tech, and repair complexity. GVs will likely have lower repair costs and more widely available parts. Specific makes and models influence insurance costs for the same reasons.
- Purchasing a vehicle requires additional costs for tax, title, and registration. Students must consider that some states (such as Oregon) do not have a sales tax. It is also essential to recognize that some states have different fee rates for GVs and EVs. In Oregon, GV fee rates are determined based on efficiency.
- It may be worthwhile to include a discussion of the value of rebates (or subsidies) in an innovation-based marketplace. Engineering students could benefit from an understanding that policy-makers can influence social forces to enable technology to gain a foothold in the marketplace, when, from a purely financial lens, the decision does not make as much sense. It is also worth noting that rebates may be a

savings for the EV purchaser, but they contribute to overall costs for society. The rebates are paid by someone, generally everyone, in the form of taxes.

Observed Student Outcomes and Reflections

Although this paper does not present formal assessment data, the in-class case study produced consistent, observable student outcomes. Many students report that it is their first experience making engineering decisions that integrate technical performance and financial feasibility rather than treating them separately. Students often enter with strong expectations about the superiority of electric vehicles and are surprised when reasonable assumptions yield ambiguous results or outcomes that are highly sensitive to policy incentives.

Informal reflections and class discussions suggest that the activity improves students' appreciation for uncertainty, assumption-driven variability, and the influence of economic constraints on design decisions. Engagement is particularly high when students justify their assumptions and compare results across groups, especially when analyses yield defensible but conflicting conclusions. These experiences support the development of economic reasoning, professional judgment, and systems thinking in the absence of a single correct answer.

Student feedback also highlights both strengths and challenges. While most students are highly engaged, some initially express discomfort with the lack of a definitive solution, particularly those accustomed to tightly constrained problems. When explicitly addressed by the instructor, this discomfort becomes a productive learning opportunity that reinforces the realities of real-world engineering analysis.

Instructors may wish to provide scaffolding for assumption selection or structured reflection prompts to help students articulate drivers of outcome differences. Varying scenarios such as geographic context, vehicle class, or policy environment can further broaden the discussion and reduce concerns about context-specific results.

Conclusion & Recommendations

This case study demonstrates how deeply intertwined technical and financial considerations are in engineering design, and why engineering students must be able to navigate both. By requiring students to construct a first-cut NPV analysis using self-selected assumptions, the activity reveals an essential truth of engineering practice: uncertainty is unavoidable, and decisions must be made anyway. Students not only observe how technical metrics (such as efficiency, performance, or energy use) shape financial outcomes, but also how financial limitations can constrain or redirect technical design options. Because each student's assumptions differ, the resulting variation in outcomes becomes a powerful teaching tool, reinforcing the importance of transparency, justification, and sensitivity analysis. Rather than converging on a single "correct" answer, students develop the habits of mind needed to reason through ambiguous, assumption-driven engineering problems.

Looking ahead, this case study can be extended in several productive ways. Instructors may introduce additional economic evaluation methods (such as Annual Equivalent Worth or Rate of Return) to deepen students' analytical and financial toolkit. Finally, the thoughtful use of Artificial Intelligence in this assignment highlights an emerging pedagogical advantage. AI can serve as a research assistant and thought partner without displacing the student's analytical responsibility. When used in this structured, intentional manner, AI enhances learning by supporting data collection while keeping the core reasoning, modeling, and decision-making squarely in the student's hands. Together, these approaches help prepare future engineers for the complexities, tradeoffs, and competing priorities inherent in real-world engineering practice.

From a pedagogical perspective, this case study embodies the principles of active, inquiry-based learning by positioning students as analysts who must gather data, evaluate competing assumptions, and defend their reasoning. Rather than passively applying formulas, students engage in authentic decision-making that mirrors professional engineering practice. They are working with incomplete information, managing uncertainty, and balancing technical and financial constraints. These features make the assignment particularly effective for developing higher-order thinking and metacognitive skills: students must articulate why they chose particular values, reflect on how those choices influence outcomes, and confront the reality that multiple defensible solutions can coexist. The structure also supports collaborative discussion, enabling instructors to facilitate conversations about variability, bias, and the interpretive nature of engineering analysis. In this way, the activity not only strengthens students' technical competencies but also nurtures the professional judgment and reflective habits essential for engineering practice.

The contribution of this work lies not in the specific numerical results of the EV–GV comparison, but in demonstrating how techno-economic case studies can serve as a flexible, scalable instructional framework for engineering economics education.

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Grammarly was used to improve the manuscript's writing. MS Copilot was used as a thought partner and information-gathering tool (specific uses are identified in the text above). MS Copilot was used to format citations for the Bibliography.

Supplementary Materials

Please get in touch with Shaz Vijlee (vijlee@up.edu) with any questions or inquiries about specific supplementary materials.

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