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Exploring Climate Policy Scenarios Using the En-ROADS Simulator: A Comparative Analysis

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Abstract*– Climate change education has shifted from simple debates to more complex decision-making processes, emphasizing local-scale solutions. Nonetheless, while discussions often focus on climate change causes and impacts, concrete solutions remain underdefined. The En-ROADS simulator, developed by Climate Interactive and MIT Sloan Sustainability Initiative, provides an interactive platform for exploring climate mitigation strategies. This study utilized En-ROADS to model two climate policy scenarios: (1) a game-based approach aligning with the simulator's suggested framework, and (2) a scenario based on the Asia Pacific Energy Research Centre (APERC) carbon neutrality proposal. The findings demonstrate that while both approaches effectively reduce projected global temperatures, the APERC-based strategy yields more significant results due to its more aggressive mitigation measures. En-ROADS proves to be a versatile educational and policy tool, fostering critical thinking and engagement in climate decision-making. Its ability to simulate diverse climate scenarios highlights its potential for supporting resource management strategies and increasing awareness of global climate change challenges.

Keywords*-- Climate change education, climate policy, En-ROADS simulator, interactive modeling, sustainability.

I. Introduction

In recent years, climate change education has evolved significantly, shifting away from "for and against" debates to a more complex, decision-making approach at the local scale. Early discussions primarily focused on understanding the science and resources available, but today, geography classrooms are incorporating climate change as part of a broader sustainability strategy. However, while much emphasis is placed on the causes and impacts of climate change, solutions remain loosely defined. In order to engage young people, policymakers, educators, and school leaders must recognize both students' and teachers' interests, moving beyond policy-heavy discussions toward active participation in climate decision-making. Despite the complexity of climate impacts and the challenge of maintaining political impartiality in classrooms, new interactive tools offer promising ways to bring these discussions to life [1].

One such tool is the EN-ROADS simulator, developed by Climate Interactive in collaboration with MIT and the Sloan Sustainability Initiative. EN-ROADS provides an accessible, data-driven platform for exploring climate solutions by modeling how various factors—such as energy efficiency, carbon pricing, and technological innovations—affect global emissions and temperature. Unlike larger climate models, EN-ROADS is designed for ease of use, requiring no specialized software or registration, making it ideal for educational settings. It allows users to test policies and investment decisions through interactive simulations, encouraging critical thinking and meaningful debate about climate action. The platform has already been widely adopted, with over 81,000 users across 86 nations, including policymakers, business leaders, and educators [2].

Despite the availability of scientific data, there remains a gap between climate science and public perception, often influenced by social and cultural beliefs. Many individuals and organizations struggle to determine effective climate actions, even though the Intergovernmental Panel on Climate Change (IPCC) has shown that a rapid transition to a low-carbon society is possible. Interactive models like EN-ROADS can help bridge this gap by providing engaging learning experiences that allow users to visualize the impacts of different policy choices. By integrating interactive simulations with scenario-building discussions, individuals can better understand the consequences of their actions and build support for effective climate policies [3].

A recent example of EN-ROADS in action was a workshop at the 2022 Ocean Sciences Meeting, where participants—including students, researchers, and scientists—used the model to explore climate policy scenarios. The workshop encouraged participants to test various actions, such as improving energy efficiency, implementing carbon pricing, and reducing deforestation, to assess their global impact. Initially, small-scale actions led to only minor improvements in projected global temperatures, highlighting the need for more comprehensive, multi-faceted strategies. Ultimately, by collaboratively building a robust climate action plan, participants gained deeper insight into the interconnected nature of climate solutions, emphasizing the importance of holistic, equity-focused approaches to achieving the Paris Agreement goals [3].

II. En-ROADS Climate Solution Simulator

The concern for synthesizing technical climate science into accessible media and leveraging the power of experiential learning to engage and inform people about equitable and high-impact climate solutions led to the development of the En-ROADS application by Climate Interactive. This initiative, part of MIT Sloan's sustainability efforts, aims to create and share tools that help people visualize connections and promote effective and equitable climate action [4].

The En-ROADS web-based simulation application is a simplified energy system model designed for the interactive exploration of possible scenarios. Its usefulness can be outlined as follows [5]:

- Dynamics of capital stock turnover.
- Growth, energy intensity, and carbon intensity.

- Effective combinations of policies focused on supply versus demand, or technology-driven versus incentive-based approaches.
- The magnitude of economic and emissions changes required to achieve climate goals.

TABLE I
SUMMARY OF DECISIONS FOR FIRST ANALYSIS

ITEM	TEAM 1	TEAM 2	TEAM 3	TEAM 4	TEAM 5	TEAM 6	ACTION
Coal	-	Tax	Tax	-	Tax	-	Tax (+-)
Renewables	-	Subsidies	-	Subsidies	Subsidies	-	Subsidies (+)
Oil	-	Tax	No Tax	-	Tax	-	Tax (-)
Nuclear	-	-	-	-	-	-	No action
Natural Gas	-	-	Subsidy	-	-	-	Subsidy (-)
New Carbon - Zero	-	Invest	Invest	-	-	-	Invest (+)
Bioenergy	Avoid	-	-	-	-	-	Tax (-)
Coal Price	Increase > $50	Increase > $50	Increase < $30	-	Increase	No Increase	Increase > $40
Energy Efficiency (Transport)	-	Promote	-	-	-	Increase	Increase (+)
Electrification (Transport)	-	Promote	-	-	-	Increase	Increase (+)
Energy Efficiency (Infrastructure & Industry)	-	Promote	-	-	-	Increase	Increase (+)
Electrification (Infrastructure & Industry)	-	Promote	-	-	-	Increase	Increase (+)
Population Growth	Avoid	-	-	-	-	-	Maintain
Economic Growth	-	-	-	-	-	Promote	Promote (-)
Deforestation	Reduce	-	-	Regulate	Reduce	Avoid	Reduce (+)
Methane and other gases	Reduce	-	Reduce	Reduce	-	-	Reduce (+)
Afforestation	Avoid	-	Reduce	Consider	Consider	Consider	Consider (-)
Technology (Carbon Removal)	-	Consider	Promote	Consider	-	-	Promote (+)

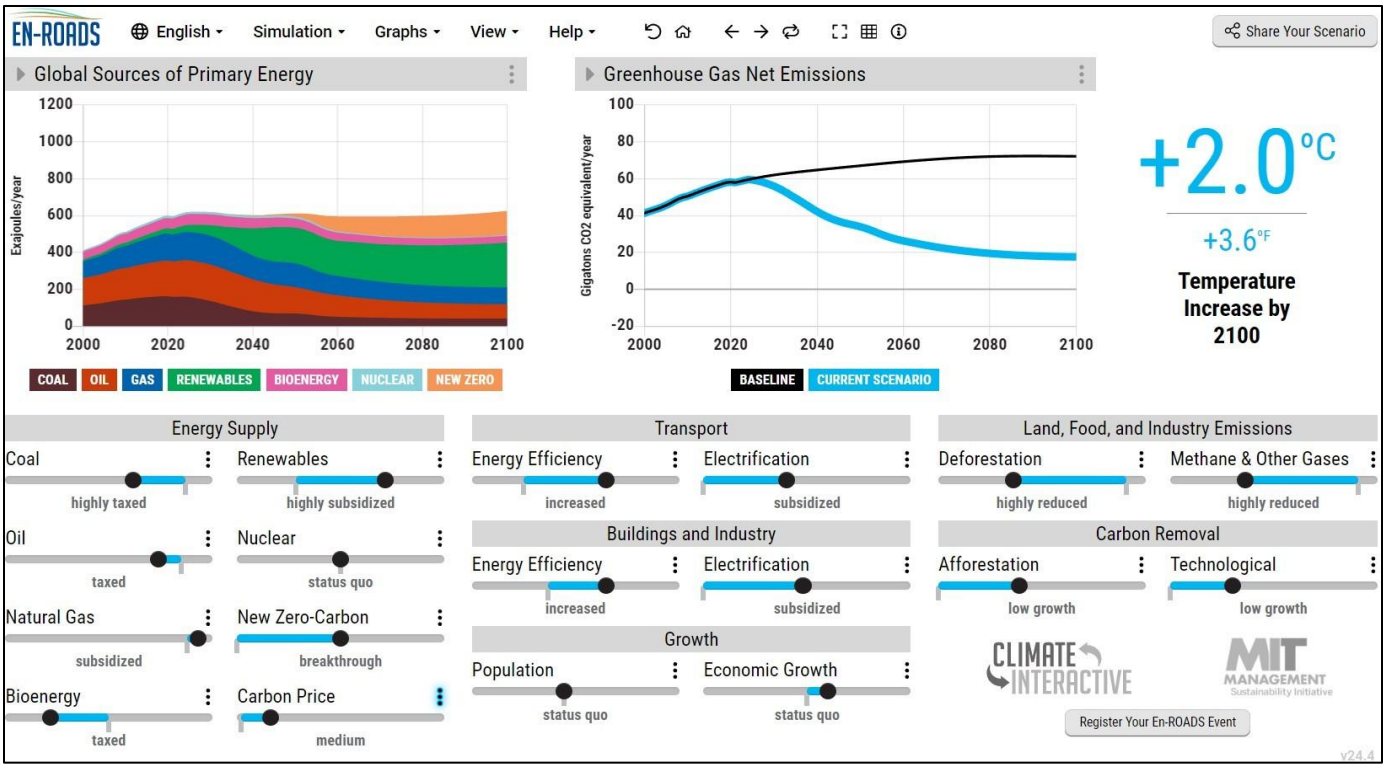

Fig. 1 Results for the First Analysis

III. First Analysis: Climate Action Simulation (En-ROADS)

The Climate Action Simulation is an interactive role-playing game designed for groups to explore the various stakeholders and solutions needed to address climate change. The game is structured as an emergency climate summit organized by the United Nations, where representatives from governments, businesses, and civil society collaborate to develop a concrete plan to limit global warming. This experience helps participants better understand the factors influencing climate change and the potential pathways to address it equitably and effectively, aligning with the international goals set in the Paris Agreement. It includes materials for both facilitators and participants, with versions for 6 and 8 teams, each assuming different roles to reach an agreement that leads to a better temperature increase trend by the year 2100 [4].

TABLE II
Summary and Conclusions of the First Analysis

ITEM	ACTION	PARAMETER
Coal	Tax (+-)	29$/tce
Renewables	Subsidies (+)	-0.03$/kWh
Oil	Tax (-)	11$/boe
Nuclear	No action	0.00$/kWh
Natural Gas	Subsidy (-)	-0.3$/Mcf
New Carbon - Zero	Invest (+)	1
Bioenergy	Tax (-)	14$/boe
Coal Price	Increase > $40	40$/ton
Energy Efficiency (Transport)	Increase (+)	2.9%/year
Electrification (Transport)	Increase (+)	20%
Energy Efficiency (Infrastructure & Industry)	Increase (+)	2.9%/year
Electrification (Infrastructure & Industry)	Increase (+)	24%
Population Growth	Maintain	10.4 billion people
Economic Growth	Promote (-)	1.7%/year
Deforestation	Reduce (+)	-6%/year
Methane and other gases	Reduce (+)	-60%
Afforestation	Consider (-)	39%
Technology (Carbon Removal)	Promote (+)	30%

A. Working Conditions for 6 Teams

This scenario involves 6 teams with clearly defined considerations. The only common goal for all teams is to reduce the temperature increase to below 2°C by 2100. The specific considerations for each team are listed below:

1) Climate Justice Hawks:

- Reduce greenhouse gas (GHG) emissions.
- Increase the carbon price (above $50 per ton), provide subsidies for renewable energy, and impose taxes on fossil fuels.
- Consider partial afforestation.
- Consider reducing other GHGs such as CH_4, NO_2, and fluorinated gases, including the use of new technologies. Avoid regulations in the agricultural sector.
- Consider subsidies for renewable energy.
- Reduce deforestation.
- Limit land use and ensure global food production. Avoid afforestation methods, biofuels, and bioenergy with carbon capture and storage (BECCS).

2) Clean Tech:

- Impose taxes on fossil fuels and increase the carbon price (above $50 per ton).
- Provide subsidies for renewable energy (wind, solar, geothermal, hydro, and storage), including technology development.
- Promote energy efficiency.
- Promote electrification of transportation.
- Invest in research and development of a low-cost, zero-carbon energy source.
- Consider partial use of carbon dioxide removal (CDR).

3) Conventional Energy Supply:

- Oppose increasing the carbon price; setting it above $25–$30 would be harmful to the fossil fuel industry.
- Oppose fossil fuel taxes, suggest subsidies for natural gas (the best transition option for this sector), and prefer carbon taxes over oil or gas taxes.
- Promote new carbon capture and storage (CCS) technologies, which can capture up to 90% of CO_2.
- Reduce sources of other GHGs, such as CH_4 and NO_2; agriculture and forest cultivation also produce GHGs.

4) Land, Agriculture & Forestry:

- Manage deforestation wisely; it should neither be excessive nor insufficient.

5) World Governments:

- Subsidize renewable energy.
- Consider taxes on fossil fuels and/or increasing the carbon price. This can be done in phases, as drastic changes are not advisable.
- Reduce other GHGs such as CH_4, NO_2, and fluorinated gases.
- Reduce deforestation.
- Consider afforestation.

6) Industry and Commerce:

- Strive to keep prices low.
- Increase energy efficiency in transportation, infrastructure, and industry.
- Explore electrification in transportation, infrastructure, and industry.

- Pursue actions that do not negatively impact the industry. Consider policies to reduce other GHGs, cut deforestation, and promote afforestation.

B. Conclusions of the First Analysis

Based on the previously discussed points, a comparative table has been created to facilitate decision-making based on the key aspects of each team.

As a result, the following parameters have been determined for updating the values in the En-ROADS application, as detailed in Table I. By updating the En-ROADS application according to the conclusions drawn from Table II, the results obtained are shown in Fig. 1.

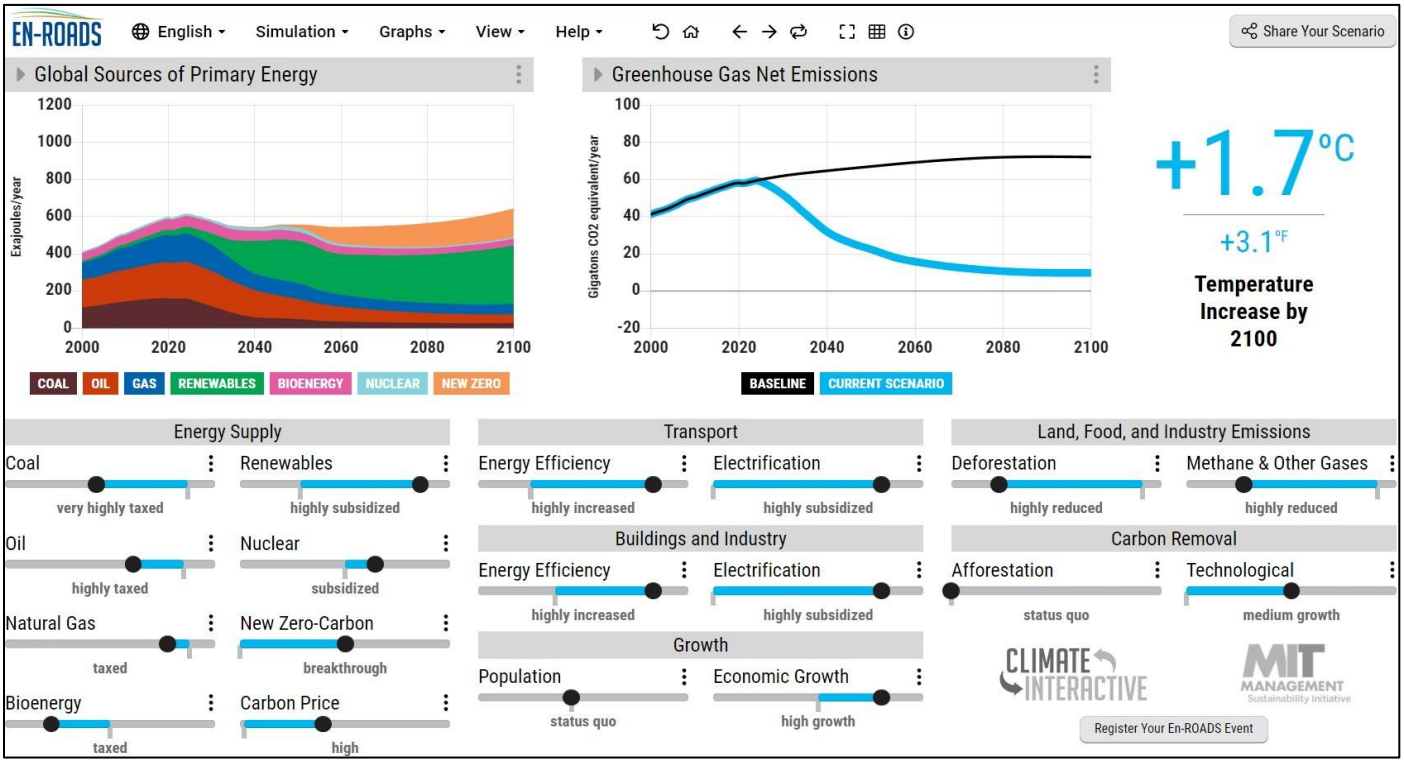

Fig. 2. Results for the Second Analysis

IV. Second Analysis: APEC Energy Demand and Supply Outlook

The APEC Energy Demand and Supply Outlook (8th Edition) 2022 offers an in-depth analysis of energy trends in the 21 APEC member economies, exploring two key scenarios. The Reference Scenario (REF), based on current policies and trends, projects a 14% increase in energy demand by 2050. In contrast, the Carbon Neutrality Scenario (CN) considers the implementation of additional measures like energy efficiency, fuel substitution, and carbon capture, aiming for a more sustainable energy future. This scenario shows a decoupling of energy demand from economic growth, emphasizing higher efficiency and lower energy intensity; where the temperature increase does not exceed 2°C by 2050 [6].

A. Projections (Characteristics)

Below are the projected conditions for a carbon-neutral (CN) scenario by 2050:

1) Macroeconomic Context:

- By 2050, GDP is projected to reach $140,000 billion (more than double the current value).
- The global population is expected to reach 3,000 million people.

2) Energy Demand:

- Electricity is expected to account for 29% to 40% of global energy consumption by 2050.
- Achieving this requires a reduction in the use of natural gas, oil, and coal.

3) Energy Demand by Sector:

- Energy consumption is expected to decline across all sectors, leading to improved energy efficiency.

4) Energy Demand in Infrastructure:

- A higher degree of electrification and reduced fossil fuel use is expected.
- There is some potential for promoting renewable energy.

5) Energy Demand in Industry:

- The scenario is similar to the infrastructure sector.

- Additionally, biomass and hydrogen energy technologies remain viable options.

TABLE III
SUMMARY AND CONCLUSIONS OF THE SECOND ANALYSIS

ITEM	ACTION	PARAMETER
Coal	Tax (+)	50$/tce
Renewables	Subsidies (+)	-0.04$/kWh
Oil	Tax (-)	24$/boe
Nuclear	Subsidy (-)	-0.02$/kWh
Natural Gas	Tax (-)	0.6$/Mcf
New Carbon - Zero	Invest (+)	1
Bioenergy	Tax (-)	14$/boe
Coal Price	Increase (+)	99$/ton
Energy Efficiency (Transport)	Increase (+)	4.0%/year
Electrification (Transport)	Increase (+)	40%
Energy Efficiency (Infrastructure & Industry)	Increase (+)	4.0%/year
Electrification (Infrastructure & Industry)	Increase (+)	40%
Population Growth	Expected	10.4 billion people
Economic Growth	Expected	1.7%/year
Deforestation	Reduce (+)	-7.5%/year
Methane and other gases	Reduce (+)	0%
Afforestation	No action	50%
Technology (Carbon Removal)	Promote (+)	30%

6) Energy Demand in Transportation:
- A drastic reduction in fossil fuel use is expected.
- The focus is on electrification, renewable energy, and hydrogen.

7) Electricity Generation:
- There is a strong push to phase out fossil fuels.
- Natural gas remains stable, with neither significant increases nor decreases.
- Nuclear energy is considered a viable option.
- Renewable energy is strongly promoted.

8) Coal in the CN Scenario:
- A drastic reduction in coal usage is expected, with a 77% decline by 2050.

9) Natural Gas in the CN Scenario:
- Slow growth initially, followed by a 24% decline by 2040.

10) Crude Oil in the CN Scenario:
- A slight decline from 2030 onwards, with a reduction of about 11%.

11) Bioenergy in the CN Scenario:
- Slight growth initially, followed by a decline near 2050, maintaining a relatively stable usage level.

12) Energy Intensity in the CN Scenario:
- Energy intensity improves, with an annual efficiency increase of 1.9%.

13) Renewable Energy Use in the CN Scenario:
- A strong increase in renewable energy use, reaching 85% by 2050.

14) CO_2 Emissions in the CN Scenario:
- By 2050, CO_2 emissions must be reduced by 62% compared to current trends.
- Emission reductions apply to agriculture, infrastructure, transportation, industry, energy, and other sectors.

15) CO_2 Capture Technologies:
- Carbon Capture and Storage (CCS) is considered, capturing up to 2.3 billion tons of CO_2 per year by 2050.

16) Electric Vehicles:
- A significant increase in electrification in transportation is expected to meet 2050 targets.

17) Nuclear Energy:
- A regulated and moderate increase in nuclear energy use is anticipated.

B. Conclusions of the Second Analysis

All the aforementioned information to achieve a carbon neutrality scenario by the year 2050 is summarized in the following Table III, which will be simulated in the En-ROADS application. Similarly, a temperature increases of equal to or less than 2°C (by 2050) is desired.

By updating the En-ROADS application according to the conclusions obtained from Table III, the results obtained in the application are shown in Figure 2.

IV. CONCLUSIONS

The En-ROADS web application, developed by the MIT Sloan Sustainability Initiative, was utilized to conduct a climate simulation that generates scenarios based on actions that could affect global climate conditions.

With the goal of reducing global temperature by 2°C by 2100, two analyses were performed:
- The first analysis was based on the game suggested by the application's creators.
- The second analysis followed the carbon neutrality proposal by APERC.

For the first analysis, a decision table (Table I) was created to compare the proposals from all teams in the "game." The findings were quantified in Table II and then simulated in En-ROADS, achieving the desired results.

For the second analysis, the APERC carbon neutrality proposal (targeted for a 2050 scenario) was summarized and then quantified in Table III. The results were more effective, but it is important to note that the proposed actions were more drastic, as the APERC proposal aims to reduce temperature by 2°C by 2050, rather than 2100.

The En-ROADS application proves to be highly versatile, capable of generating a wide range of climate change scenarios. This flexibility not only helps in developing proposals for resource management and policy-making but also plays a crucial role in raising awareness about global climate change.

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