1. “Soft” and “Hard” Energy Paths

Thirty-eight years ago, Amory Lovins wrote his seminal piece describing “hard” and “soft” energy paths. In this question, we would like you to consider Lovins’s arguments in the context of important energy issues today, as well as compare the Lovins paper with some of the articles you’ve read concerning energy and development. [25 points]

a) Describe Lovins’s distinction between hard and soft paths in a few paragraphs using your own language. (It’s OK to take short quotations from Lovins but we’d like to have you explain the concepts in your own words.) [4 points]

b) Pick a recent article from any major newspaper that addresses a contemporary energy issue and in a short paragraph comment on whether you think the issue is in the “hard-path” or “soft-path” approach. Please start by including a citation for your article, and a sentence summarizing its main point. [6 points]

c) “Hard” and “soft” are relative terms, and the same energy technology can be applied in ways that are consistent with either the hard- or the soft-path approach. Take the energy issue you worked with in part b) and describe in a sentence or two how the issue might be affected by a “softer” approach (if you identified it as a hard-path approach) or a “harder” approach (if you identified it as a soft-path approach) than what was discussed in the article you read. [4 points]

d) List the five fallacies in the “Mundane Science” article by Kammen and Dove, and discuss any connection between the points raised by Lovins and the five fallacies. [6 points]

e) The Lovins piece is focused on energy in the context of the United States. How applicable do you believe the concepts and arguments he uses are to energy-impoverished, developing countries (as in, those countries with average annual per capita energy consumption rates under 1 TOE)? [5 points]

2. Exponential growth models

The OECD (or broadly speaking developed) nations’ energy consumption and CO2 emissions have stabilized in recent years, while those for non-OECD (or broadly speaking developing) nations have been steadily growing. This is of major concern in the context of global coordination in mitigating climate change. BRIC (Brazil, Russia, India, and China) are some of the largest economies in the non-OECD category. The following table is taken from the BP Statistical Review of World Energy. [20 points]

<table>
<thead>
<tr>
<th>Year</th>
<th>United States</th>
<th>Brazil</th>
<th>Russia</th>
<th>India</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>6377</td>
<td>352</td>
<td>1556</td>
<td>953</td>
<td>3430</td>
</tr>
<tr>
<td>2013</td>
<td>5931</td>
<td>541</td>
<td>1714</td>
<td>1931</td>
<td>9524</td>
</tr>
</tbody>
</table>

growth rate, \(r\) 3.3%
a) Referring to the exponential growth model as \( Q_n = Q_0 \exp(r \times n) \) or \( r = \frac{\ln(Q_n/Q_0)}{n} \), find the rate of growth \( r \) for each country (on an annual percentage basis, up to 3 significant figures) for the \( CO_2 \) emissions between 2000 and 2013. Show your working steps and fill the table. [8 points]

b) Based on your exponential growth model in part a), which year did China pass the United States to be the world’s largest carbon dioxide emitter? Which year will India have more annual carbon dioxide than the United States? Note: round the year to the larger integer; if \( n=2022.2 \), \( n=2023 \). [8 points]

Note: \( \ln(A/B) = \ln A - \ln B \)

c) Are your carbon dioxide emissions projections for China and India realistic? State any two reasons that may not lead to these projections. (Hint: the IPAT equation). [4 points]

3. Energy, poverty and gender
The chapter “Energy and Poverty” from the 2002 World Energy Outlook, states “...the transition from traditional biomass use to full dependence on modern energy forms is not a straight-line process.” Please write two short paragraphs on each of the following questions. [25 points for ER100/PP184; 35 points for ER200/PP284]

a) Energy Transitions: What is a linear transition model? Using examples from the “Energy and Poverty” chapter and from other readings (e.g. Crewe, Lovins), comment on why energy transitions may not always be linear. In your answer, carry out one small back-of-the-envelope calculation to show how economic trade-offs may influence poor people’s energy choices. For example, you might compare the relative costs of energy (for cooking or heating) delivered by different technologies. [15 points]

b) Energy Technology Adoption: List at least three factors that are important for increasing energy technology adoption by the rural and urban poor, and provide a one sentence explanation of the importance of each factor. Do you think lessons from cookstove dissemination programs can be applied to other small-scale renewable energy technologies? Justify your answer. [10 points]

c) [ER200/PP284 only] From the energy ladder graphics, what inferences can be gleaned about social inequalities that might be inherent in climbing the energy ladder? (Hint: An increase along the y-axis is an increase in cost.) Be sure to use specific material from the readings. [10 points]

4. Combustion and electricity generation
According to the BP Statistical Review of World Energy, fossil fuels (coal, oil, and natural gas) are the dominant (about 86.7%) energy sources for the world’s 12.7 btoe (billion tons of oil equivalent) primary energy consumption in 2013. Similarly in the United States, 86.4% of the 2.27 btoe primary energy consumption is from fossil fuels. In this problem we will examine the energy and carbon emissions from generating electricity using these fuels. Assume energy density for coal and natural gas to be 29.3 MJ/kg and 50.0 MJ/kg respectively. [30 points total for ER100/PP184; 40 points total for ER200/PP284]

a) Based on an approximate formula for coal \( (C_{H_{0.8}}O_{0.1}) \), and an approximate formula for natural gas \( (C_{H_{1}}) \), write the balanced combustion equations for each fuel. (Assume complete combustion in oxygen). What is the \( CO_2 \) emission factors for coal and natural gas in kg/GJ? [8 points]

b) Assume that the efficiency of a new coal power plant is 33% and that of a natural gas combined cycle plant is 45%. What is the mass of carbon dioxide released per kWh of electricity generated from each plant. In the context of climate change, which one is a cleaner fuel and what attributes of the fuel make it so? [8 points]
c) If a household, living in a region powered by coal-fired power plant, consumes 12,000 kWh of electricity per year, what are the annual CO₂ emissions (metric tons) attributed to that household's consumption? The same household later moved to a greener region, where half of the electricity is generated from natural gas power plant and the other half from non-carbon sources, what are the annual CO₂ emissions (metric tons) with the same annual electricity consumption? Assume the power plant efficiency as in part b) and Transmission and Distribution (T&D) loss of 10%. [5 points]

d) The United States generated 1586 TWh of electricity from coal in 2013 (Source: EIA Electric Power Monthly). Assume that the average efficiency of coal-fired plants in the US is 33%. How much coal (in kilograms) was used to produce this amount of electricity? If we pile this amount of coal on a football field (area of 5500 m²), what will be the height (km) of this pile? (No fancy cones, just assume the pile has rectangular sides that go straight up) Assume coal has a density of 2200 kg/m³. [5 points]

e) You are also told that the total nameplate capacity of all coal-fired power plants in the United States is about 306 GW as of end of December 2013. What is the average capacity factor of coal power plants in 2013? [4 points]

f) [ER200/PP284 only] Our university just bought a gas combined heat and power plant (CHP), which can produce 12 GJ of heat per hour for steam generation and 2 MW of electricity at the same time. The sales engineer claimed that the Total System Efficiency can be 60-80%, which agreed with US EPA's description. But some people were skeptical about this ultra-high efficiency compared with 33% efficiency from a coal-fired power plant. You researched about the definition of Total System Efficiency (TSE) and Effective Electric Efficiency (EEE) on the above EPA website and its related content, where a boiler efficiency of 0.80 is assumed. What are the TSE and the EEE for CHP with the following operation data? [5 points]

Fuel input: 0.56 metric ton of natural gas per hour
Electricity output: 2.0 MW
Heat output for steam generation: 12 GJ per hour

[ER200/PP284 only] In the 2014 BP data, the CO₂ emission factor for coal was assumed to be 94.6 kg/GJ. And you found the following table for different types of coals in the IEA Energy Statistics Manual. Why is the Net Calorific Value (NCV) lower than the Gross Calorific Value (GCV)? Based on the values from the table, what type of coal is this BP's value likely to be? [5 points]

<table>
<thead>
<tr>
<th>(kg/GJ)</th>
<th>Carbon content</th>
<th>Moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite</td>
<td>0.778 – 0.782</td>
<td>0.10 – 0.12</td>
</tr>
<tr>
<td>Coking coals</td>
<td>0.674 – 0.771</td>
<td>0.07 – 0.09</td>
</tr>
<tr>
<td>Other bituminous</td>
<td>0.590 – 0.657</td>
<td>0.13 – 0.18</td>
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