TECHNOLOGY-POLICY DRIVEN POTENTIAL FOR DECARBONIZATION OF THE US

Frank H. Ling,[1,2] Jenn Baka,[3] and Daniel M. Kammen[1,2,3]

RAEL

[1] Renewable and Appropriate Energy Laboratory, UC Berkeley; [2] Energy and Resources Group, UC Berkeley; and [3] Goldman School of Public Policy, UC Berkeley, California 94720

Abstract: Today, there is scientific consensus that worldwide emissions reductions of at least 80% are needed by mid-century in order to avoid irreversible climate change. To fully examine the opportunities for dramatic decarbonization of the energy economy, scenarios based on the learning curves of key energy technologies are needed to compare the relative costs and benefits of different future projections. Despite under-funding, the history of investment in energy innovation demonstrates that enormous gains can be achieved for both energy efficiency and production through research programs that have been linked to implemented policies. Through incremental development and deployment of innovations in end-use efficiency, renewable energies, nuclear power, vehicle design, bio-fuels, and engine technologies; reductions of more than 80% from today's levels can be achieved by 2050.

Introduction

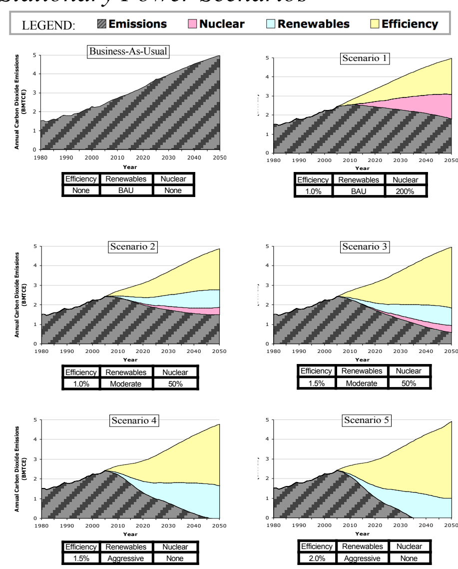
Mounting evidence for climate change and geopolitical rivalry for oil show that the business-as-usual policies of energy development are unsustainable. The US today emits 6 gigatons of greenhouse gas (GHG) emissions each year and is on a path of increased energy consumption and emissions: 1.5% annual growth in energy use with 136 quads consumed in 2025 and 190 quads consumed in 2050 unless efforts are made to reduce demand growth and deploy alternative energy. Yet, the country already possesses the technological and industrial know-how to reduce emissions to levels that will avoid permanent climate change.

Research Goals

We demonstrate dramatic but achievable scenarios for decarbonization in two of the largest sectors of the US economy: stationary power (electricity) and light vehicle transportation, which account for 20% and 40% of nation's emissions respectively. This framework is used to compare the costs and benefits of the scenarios.

	Stationary Power	Transportation
Primary Fuel	Coal	Petroleum
Decarbonization Options	End-Use Efficiency	Fuel Economy
	Renewable Energy	Biofuels
	Nuclear	Electric Hybrids

Stationary Power Scenarios



- Emissions reductions of over 80% from today's levels by 2050 are realizable through different combinations of efficiency, renewable energy, and nuclear power.
- Energy efficiency has been and is arguably the easiest and most inexpensive way for reducing energy consumption (PCAST 1997).
- All scenarios show positive returns in capital costs through fuel savings.
- Aggressive efficiency alone can maintain emissions at current levels.
- Nuclear power, while controversial, remains an economical option for producing emissions free power (MIT 2003, Hultman, Koomey, & Kammen 2007).
- Scenarios show that policy innovation needed to achieve market transformations in major energy industries.

Cost Benefit Analysis

	200 5	202 5					
		BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Annual Electricity Generated (terawatt hours)	400 0	560 1	455 4	455 4	411 5	411 5	371 5
Annual Fuel Costs (2005 $billion)	5 7	9 1	5 6	4 3	3 5	2 4	1 7
Cumulative Fuel Costs since 2005 (2005 $billion)	-	156 5	119 6	105 1	970	859	781
Cumulative Capital Costs since 2005 (2005 $billion)	-	193	106	289	288	459	459
Emissions (gigatons carbon)	2.43	3.72	2.36	1.86	1.49	1.02	0.68
Cumulative emissions since 2005 (gigatons carbon)	-	63.5	52.1	45.8	42.1	37.1	33.5

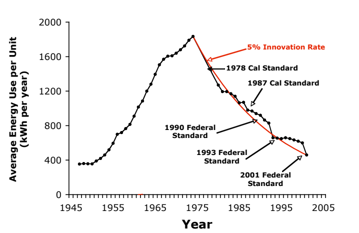
Historical Innovations

Sustained periods of innovations in energy have been observed for various technologies and economies:

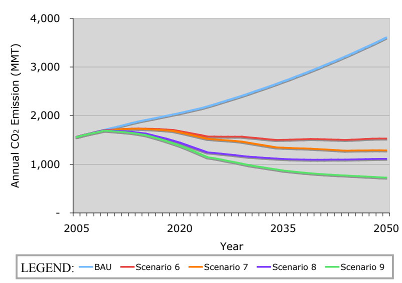
	Metric	Interval	% Change/year
Energy Production			
Photovoltaic Cells	$ / W installed	1955 - 2005	8.8
Wing Turbine	$ / W installed	1985 - 2000	3.6
Gas Turbine	$ / W installed	1958 - 1980	9.2
Ethanol Fuel	$ / m3	1975 - 2002	6.0
Energy Consumption			
Refrigerators	Energy Use / Unit	1975 - 2001	5.0
Gas Furnaces	Energy Use / Unit	1972 - 2000	2.5
Central Air Conditioning	Energy Use / Unit	1972 - 2001	2.1
CFL Ballasts	Cost / Unit	1986 - 1997	9.5
Energy Intensity			
US	Energy Use / GNP	1975 - 2001	2.9
US	Energy Use / GNP	1981 - 1986	3.4
US	Energy Use / GNP	1997 - 2001	2.7
California	Energy Use / GSP	1981 - 1986	4.5
California	Energy Use / GSP	1997 - 2001	3.9
China	Energy Use / GNP	1981 - 1986	4.8
China	Energy Use / GNP	1987 - 1996	5.0
China	Energy Use / GNP	1997 - 2001	5.3

Kammen and Ling, *in preparation*

Continued efforts in efficiency have led to dramatic reductions in end-use technologies. For example, refrigeration units have decarbonized 5% a year over the past three decades:

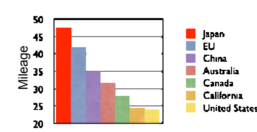


Transportation Scenarios



	Fuel Economy	Biofuel (Ethanol)	Hybrid
BAU	20 mpg	3%	None
6	Moderate	Moderate	Moderate
7	Moderate	Aggressive	Aggressive
8	Aggressive	Moderate	Aggressive
9	Aggressive	Aggressive	Aggressive Plug-In

- Mileage standards alone are the fastest option for reducing emissions.



- Over half of vehicles in Brazil can run on ethanol made from sugar cane (DOE 2006).
- Drastic reductions in emissions will require the development of cellulosic technology for producing bio-ethanol (Farrell et. al. 2006).

The Case for Energy Efficiency

- Per capita electricity consumption in California has been constant since 1975, U.S. average has grown by 2% per year.
- Under best practices, drastic gains in efficiency are realizable

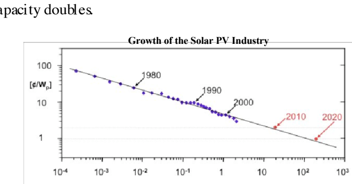
	Incandescent	Compact Fluorescent Lightbulb (CFL)	Light Emitting Diode (LED)
Luminosity (Lumens/W)	10-15	50-60	100-200
Lifetime	1000 hrs	10,000 hrs	50,000 hrs
Energy Savings	-	2/3	80-90%
Deployment	Current	Emerging	Within Decade

Efficiency Improvements in Lighting Technology

End Use	Potential Reduction
Space Heating	60%
Space Cooling	40%
Water Heating	75%
Lighting	90%
Refrigeration	3% per year
Other	5% per year

Competitive Renewable Energy

- Both wind and solar PV energy production have been growing at 30% over the past few years globally.
- Price per watt of installation decreases by 20% when production capacity doubles.



Renewable and Appropriate Energy Laboratory (RAEL), University of California, 310 Barrows Hall, Berkeley, CA 94720-3050
Website: http://rael.berkeley.edu, E-mail: kammen@berkeley.edu

A WIND ENERGY BLUEPRINT FOR POLICY MAKERS

Case study: Santa Barbara County, CA

Daniel S. Prull,[1,2] Frank H. Ling,[1,3] Adriana Valencia,[1,3] and Daniel M. Kammen[1,3,4]

[1] *Renewable and Appropriate Energy Laboratory, UC Berkeley;* [2] *Department of Mechanical Engineering, UC Berkeley;* [3] *Energy and Resources Group, UC Berkeley; and* [4] *Goldman School of Public Policy, UC Berkeley, California 94720-3050*

Abstract: Over the past 5 years wind power has been one of the fastest-growing energy sources worldwide with an annual average growth rate of 28%. In 2006, 3,400 megawatts (MW) of new capacity are expected in the United States alone, representing a 40% growth rate. At a present cost of 3 to 7 cents per kilowatt hour, wind energy has become a viable option in the energy market. Despite this rapid growth, many city and county policy makers know little about their local potential for wind development. As a case study, a wind energy blueprint was created for Santa Barbara County, California. A detailed GIS analysis shows that Santa Barbara County has a gross onshore wind resource of over 1400 MW (with a ~32% capacity factor) although only 10-12% is suitable for utility-scale development (class 3 winds or higher). This 500 MW resource represents 1.5 million tons of avoided CO_2 emissions resulting from coal fire electrical production each year.

Introduction

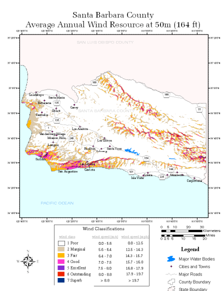
Towards a future with lower greenhouse gas (GHG) emissions, renewable energy shows enormous potential to meet growth in energy demand and replace existing fossil fuel based sources. Today, global wind industry is growing at over 28% annually and is competitive with electricity generated by natural gas powered turbines (average of 5¢/kWh with 1.7¢/kWh production tax credit) . While wind could theoretically supply all electricity consumed by the United States, the country obtains less than 1% of its power from this renewable source. As a case study, the wind resource of Santa Barbara County was studied for its potential to meet energy needs and lower GHG emissions.

Research Questions

- Quantify technical potential of residential and utility-scale wind turbines in Santa Barbara County and the Channel Islands in terms of energy output and greenhouse gas reductions
- Determine 'top site' list for utility-scale wind farms in Santa Barbara County and the Channel Islands

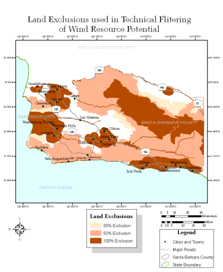
Methods

Wind maps were created using ESRI's ArcMap geographic information system (GIS) visualization tool to analyze NREL wind data. The graphical version of the data:



- Has 200 m X 200 m resolution
- Shows regions of contiguous annual average wind speed
- Is broken into 7 wind classes
- Taken at 50 m height

Filters are applied to remove unusable land for wind development. Three filters are applied:



- 100% Exclusions:

  National Park Service, Fish and Wildlife Service, State and Environmental Lands, Wildlife, Wilderness and Recreation Areas on Federal Land, Urban Areas, Airports, Wetlands, Major Water Bodies, Rivers and Streams and Shorelines

- 92% Exclusions:

  Slope >20%, (~8% of mountainous regions)

- 50% Exclusions:

  Remaining U.S. Forest Service and Department of Defense (DOD) Land, Non-Mountainous Forests

Key Policy-Making Results:

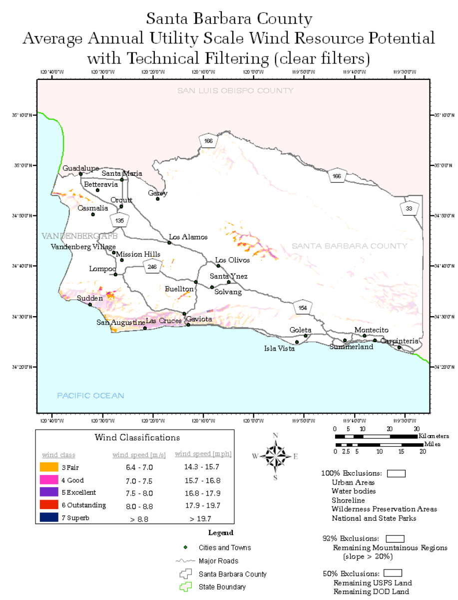
- Santa Barbara County onshore gross wind resource: 12,500 GWh
- Technical (filtered) onshore wind resource: 1,400 GWh

What does this mean for Santa Barbara County?

- Santa Barbara County Electricity Demand: 2,750 GWh (CEC, 2000)
- 51% of County's electricity demand could be met from onshore winds alone
- This is enough power to meet the demand for all 148,000 residential customers and 32% of commercial customers in the County
- This renewable energy source would reduce County CO_2 emissions by over 1.5 million tons per year (assuming 2.37 lb CO_2/kWh Wilson et. Al., 2003)
- This new wind addition could result in over 1,800 jobs within the County (BBC Research and Consulting, 2001)

	Wind Classes	% of Total Land Area	Wind Turbines	Maximum Annual Energy Production (GWh)	Minimum Annual Energy Production (GWh)	Average Annual Energy Production (GWh)
HWS Regions	5, 6, 7	0.12	GE 2.5xl	201	176	188
			Nordex N80/2500	238	201	220
LWS Regions	3, 4	0.96	Vestas V-82 1.65 MW	1318	1157	1238
			Gamesa Ecola G87 - 2.0MW	1283	1106	1195
			2.5 MW Liberty–C93	1309	1117	1213

Utility-Scale Technical AEP for Mainland Santa Barbara County



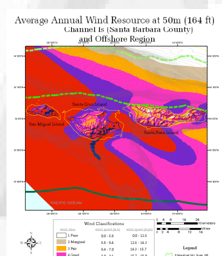
Offshore Potential

Offshore Wind Farm Assumptions (based on view-shed, marine life and transmission):

- 100% Exclusions: 0 to 5 nautical miles
- 67% Exclusions: 5 to 20 nautical miles
- 33% Exclusions: 20 to 50 nautical miles
- Over 160,000 GWh of wind potential

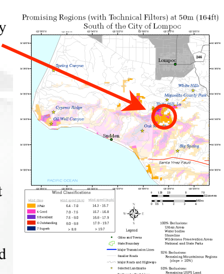
Current economically achievable depths of 30 meters or less (yellow curve) (Musial and Butterfield, NREL)

Offshore wind-farm in Horns Rev, Denmark



Current Wind Farm Development

- Area near La Tinta Hill is currently under review for development by Pacific Renewable Energy Generation LLC
- The proposed farm would consist of approximately 60 utility-scale turbines providing 80-120 MW
- As part of the proposal, new transmission would need to be built between the project site to a PG&E substation in nearby Lompoc
- Hundreds of MW of potential wind generation close-by

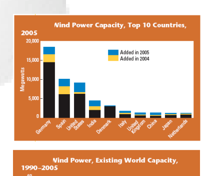


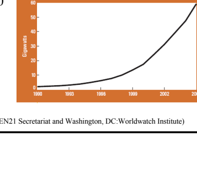
CA GHG Emissions Polices

- AB 1493 (Pavley):
  30% Reduction in automobile GHG emissions (MY 2025)
- Executive Order S-3-05:
  Statewide GHG emission reduction targets (~25% in 2020)
- AB 1007 (Pavley 2):
  Developing a comprehensive strategy to address alternative fuels
- AB 32 (California Global Warming Solutions Act):
  25% reduction in GHG emissions by 2020
- Executive Order 06-06:
  Statewide biofuels production targets (40% in 2020)

Wind Facts for Policy Makers

- Worldwide annual investment in new renewable capacity: $38 billion in 2005
- Existing renewable capacity: 182 GW (totaling ~4% of global power sector)*
- Developing countries account for 70% of this capacity
- Existing wind power capacity: 59 GW
- 28% annual wind power growth from 2000 – 2004
- Germany leads capacity with 17 GW installed (with less of a wind resource than North Dakota)





*excluding large hydro-power

REN21. 2006. "Renewables Global Status Report 2006 Update" (Paris: REN21 Secretariat and Washington, DC:Worldwatch Institute)

Renewable and Appropriate Energy Laboratory (RAEL), University of California, 310 Barrows Hall, Berkeley, CA 94720-3050
Website: http://rael.berkeley.edu, E-mail: kammen@berkeley.edu