Questioning the carbon effectiveness of nuclear power

Invited Presentation to the "Nuclear Power in a Time of Global Climate Change" Conference, Prague, Czech Republic, October 6, 2020

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Director of the Sussex Energy Group

Director of the Center on Innovation and Energy Demand

Aim for this presentation:

- (Quickly?) provide an objective, dispassionate, and nonpartisan assessment of the carbon footprint and mitigation potential for nuclear power
- I have no stake other than as an interested citizen or agnostic scholar
- All of the data utilized is fully peer-reviewed, cited and fully open access, part of a dataset in the public domain, or part of a dataset publicly available in an appendix to an article published

First assessment: a “critical” survey

Centre on Innovation and Energy Demand

Energy Policy 36 (2008) 2940–2953

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

ELSEVIER

Valuing the greenhouse gas emissions from nuclear power: A critical survey

Benjamin K. Sovacool *

- Screened 103 lifecycle estimates of the carbon footprint of nuclear power
- Excluded 84 based on
  - Date (too old)
  - Scope (did not detail emissions for the lifecycle)
  - Method (did not present new data)
  - Accessibility (did not release data, or not in English)

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ENERGY POLICY

Valuing the greenhouse gas emissions from nuclear power: A critical survey

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The remaining 19 studies met all criteria, and were:

- Published in the past 10 years
- Accessible to the public
- Transparent about their methodology
- Provided clear estimates of equivalent greenhouse gas emissions according to the separate parts of the nuclear fuel cycle.

Studies were “weighed” equally, and not normalized or altered

First assessment: a “critical” survey

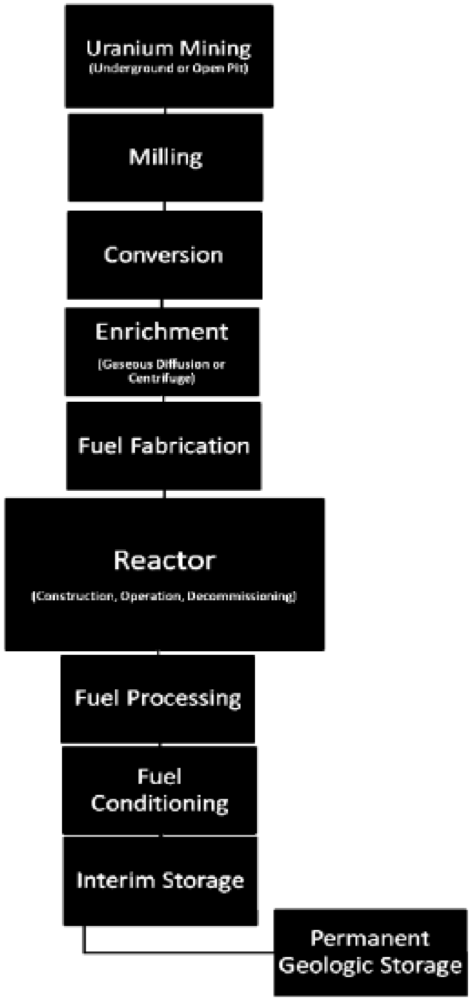

Fig. 1. The “once-through” nuclear fuel cycle.

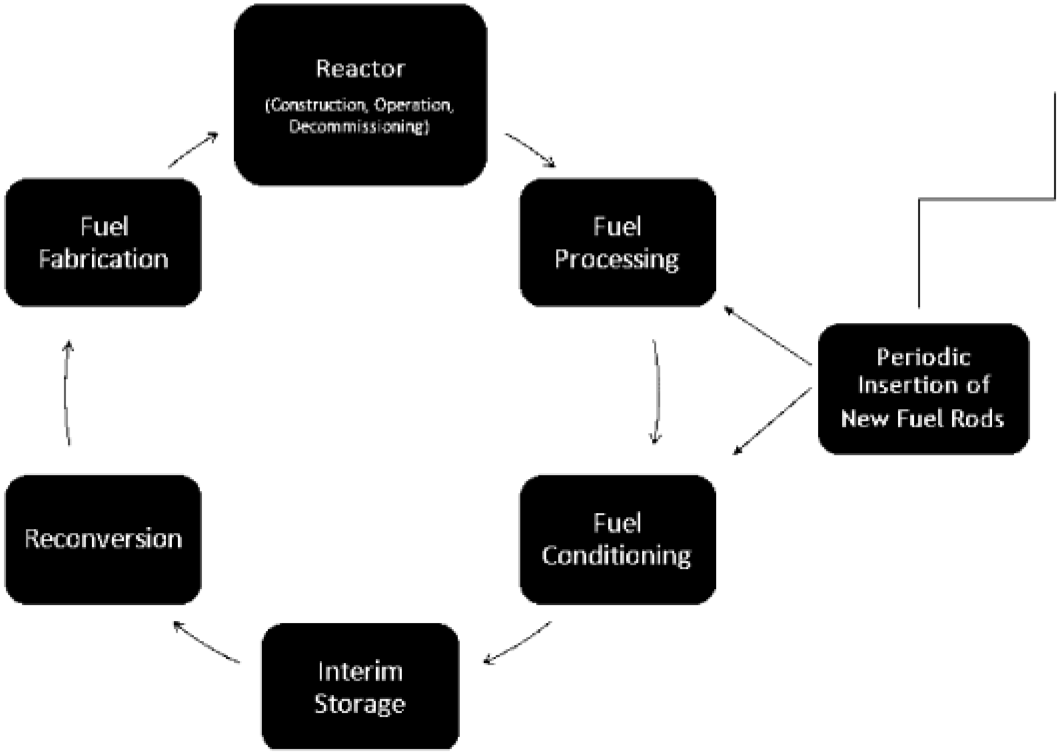

Fig. 2. The “closed” nuclear fuel cycle.

Source: Sovacool, BK. “Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey,” *Energy Policy* 36 (8) (August, 2008), pp. 2940-2953.

First assessment: a "critical" survey

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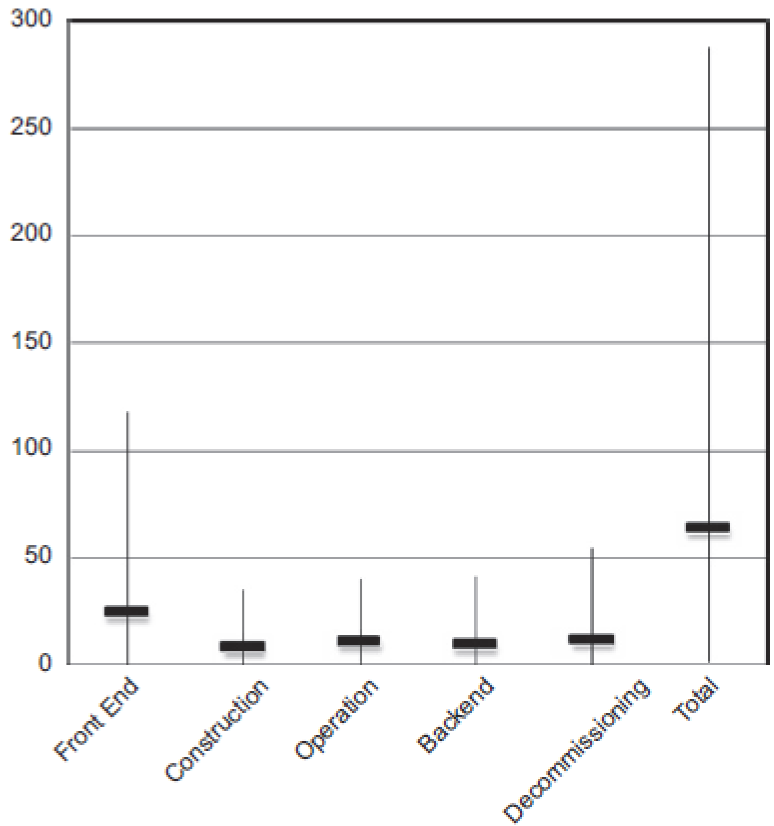

Fig. 3. Range and mean emissions reported from qualified studies for the nuclear fuel cycle (g CO_2e/kWh)

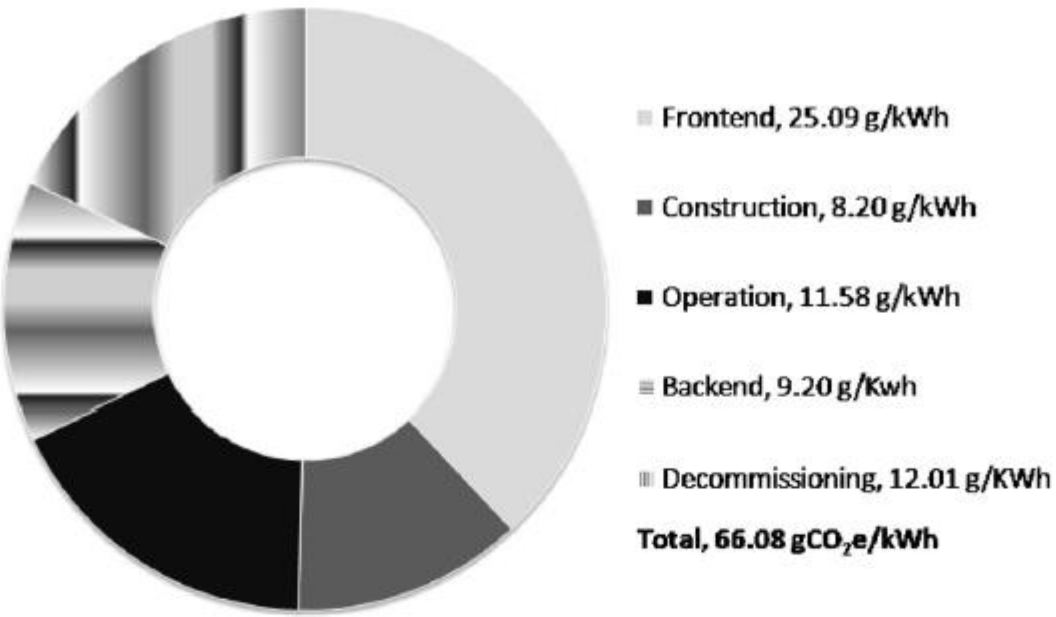

Fig. 4. Mean emissions reported from qualified studies for the nuclear fuel cycle (g CO_2e/kWh).

Source: Sovacool, BK. "Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey," *Energy Policy* 36 (8) (August, 2008), pp. 2940-2953.

Confirmatory evidence

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Energy Policy 37 (2009) 5056–5068

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Greenhouse gas emissions in the nuclear life cycle: A balanced appraisal

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A R T I C L E I N F O

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Keywords:
Greenhouse gas emissions
Life-cycle assessment
Nuclear

A B S T R A C T

In order to combat global warming, a detailed knowledge of the greenhouse gas (GHG) emissions associated with different energy conversion technologies is important. For nuclear energy, GHG emissions result from different process stages of the whole fuel cycle. A life-cycle assessment offers the possibility to properly calculate these emissions. In the past, both indirect energy use and GHG emissions were studied by many researchers. Most of the studies result in low indirect emissions comparable to wind turbines. However, some of the studies in the literature obtain high results adding up to a significant fraction of the direct emissions from a CCGT.

In this paper, the GHG emissions resulting from the overall nuclear fuel cycle are analyzed by making a detailed comparison of the results from three different life-cycle assessments. Hereby, the studies are chosen in order to reflect the range of results available in open literature. The studies under consideration result in indirect emissions of around 8 and 58 g CO_2/kWh_e and more than 110 g CO_2/kWh_e.

An explanation is given for these strongly varying results by analyzing the input data, assumptions and estimations made for different process steps.

Confirmatory evidence

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RESEARCH AND ANALYSIS

Life Cycle Greenhouse Gas Emissions of Nuclear Electricity Generation

Systematic Review and Harmonization

Ethan S. Warner and Garvin A. Heath

Keywords:

environmental impact assessment
industrial ecology
life cycle assessment
light water reactor
meta-analysis
nuclear power

Supplementary material is available on the JIE Web site

Summary

A systematic review and harmonization of life cycle assessment (LCA) literature of nuclear electricity generation technologies was performed to determine causes of and, where possible, reduce variability in estimates of life cycle greenhouse gas (GHG) emissions to clarify the state of knowledge and inform decision making. LCA literature indicates that life cycle GHG emissions from nuclear power are a fraction of traditional fossil sources, but the conditions and assumptions under which nuclear power are deployed can have a significant impact on the magnitude of life cycle GHG emissions relative to renewable technologies.

Screening 274 references yielded 27 that reported 99 independent estimates of life cycle GHG emissions from light water reactors (LWRs). The published median, interquartile range (IQR), and range for the pool of LWR life cycle GHG emission estimates were 13, 23, and 220 grams of carbon dioxide equivalent per kilowatt-hour (g CO_2-eq/kWh), respectively. After harmonizing methods to use consistent gross system boundaries and values for several important system parameters, the same statistics were 12, 17, and 110 g CO_2-eq/kWh, respectively. Harmonization (especially of performance characteristics) clarifies the estimation of central tendency and variability.

To explain the remaining variability, several additional, highly influential consequential factors were examined using other methods. These factors included the primary source energy mix, uranium ore grade, and the selected LCA method. For example, a scenario analysis of future global nuclear development examined the effects of a decreasing global uranium market-average ore grade on life cycle GHG emissions. Depending on conditions, median life cycle GHG emissions could be 9 to 110 g CO_2-eq/kWh by 2050.

Confirmatory evidence

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ENERGY POLICY

Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey

CrossMark

Daniel Nugent [a], Benjamin K. Sovacool [a,b,*]

Second assessment: same technique applied to renewables, shows nuclear in comparative light

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Table 13
Comparative lifecycle estimates for sources of electricity.

Technology	Capacity/configuration/fuel	Mean estimate (g Co_2e/kWh)
Hydroelectric	3.1 MW, Reservoir	10
Biogas	Anaerobic Digestion	11
Hydroelectric	300 kW, Run-of-River	13
Solar Thermal	80 MW, Parabolic Trough	13
Biomass	Forest Wood Co-combustion with hard coal	14
Biomass	Forest Wood Steam Turbine	22
Biomass	Short Rotation Forestry Co-combustion with hard coal	23
Biomass	Forest Wood Reciprocating Engine	27
Biomass	Waste Wood Steam Turbine	31
Wind	Various sizes and configurations	34
Biomass	Short Rotation Forestry Steam Turbine	35
Geothermal	80 MW, Hot Dry Rock	38
Biomass	Short Rotation Forestry Reciprocating Engine	41
Solar Photovoltaic	Various sizes and configurations	50
Nuclear	Various reactor types	66
Natural Gas (Conventional)	Various combined cycle turbines	443
Natural Gas (Fracking)	Combined cycle turbines using fuel from hydraulic fracturing	492
Natural Gas (LNG)	Combined cycle turbines utilizing LNG	611
Fuel Cell	Hydrogen from gas reforming	664
Diesel	Various generator and turbine types	778
Heavy Oil	Various generator and turbine types	778
Coal	Various generator types with scrubbing	960
Coal	Various generator types without scrubbing	1,050

Source: Nugent, D and BK Sovacool. "Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey," Energy Policy 64 (February, 2014), pp. 229-244.

Third assessment: construction overruns and delays

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Energy 74 (2014) 906–917

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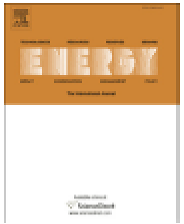

Risk, innovation, electricity infrastructure and construction cost overruns: Testing six hypotheses

CrossMark

Benjamin K. Sovacool [a, b, *], Alex Gilbert [b], Daniel Nugent [b]

Energy Research & Social Science 3 (2014) 152–160

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journal homepage: www.elsevier.com/locate/erss

ELSEVIER

Original research article

An international comparative assessment of construction cost overruns for electricity infrastructure

CrossMark

Methods

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• An original dataset of 401 separate power plant and transmission projects spread across 57 countries representing almost $820 billion worth of investment and 343,336 MW of installed capacity.
• Costs are underestimated in three out of every four projects
• 75.1 percent of projects in the sample experienced a cost overrun (only 39 projects across the entire sample have no cost overrun or an underrun)
• Mean construction time was 73.4 months and the average cost overrun per project was almost $1 billion, indicating a mean cost escalation of 66 percent per project.

Table 1: Summary Cost Overrun Data for Electricity Projects by Source

Project type	Number of projects (N)	Average cost escalation (%)	Standard deviation	Average cost overrun (m$)	Standard deviation	Average time overrun (%)	Standard deviation	Average time overrun (months)	Standard deviation
Hydroelectric dam	61	70,6	111,7	2437	7054,7	63,7	89,8	43,2	58,4
Nuclear reactor	180	117,3	152,1	1282	1965,8	64	53,1	35,7	30,6
Thermal plant	36	12,6	33,5	168,5	579,6	10,4	19,0	4,8	8,9
Wind farm	35	7,7	13,1	32,8	112,9	9,5	22,6	0,22	2,4
Solar facility	39	1,3	17,8	-4,2	62,1	-0,2	8,0	-0,2	2,1
Transmission	50	8	40,4	29,7	217,6	7,5	30,6	3,5	12,8

Mean Time Overruns and Percentage of Projects with a Cost Overrun for Electricity Infrastructure by Reference Class

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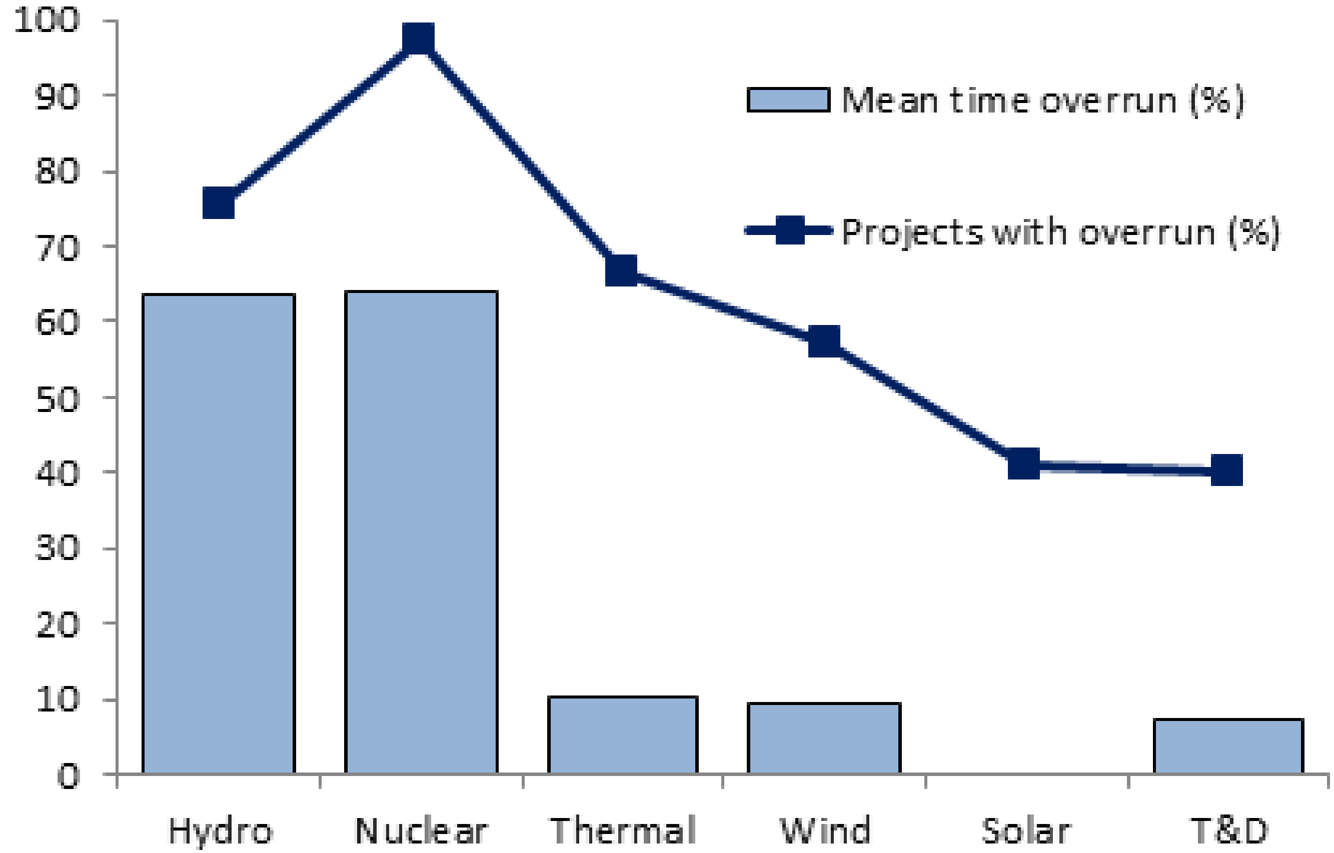

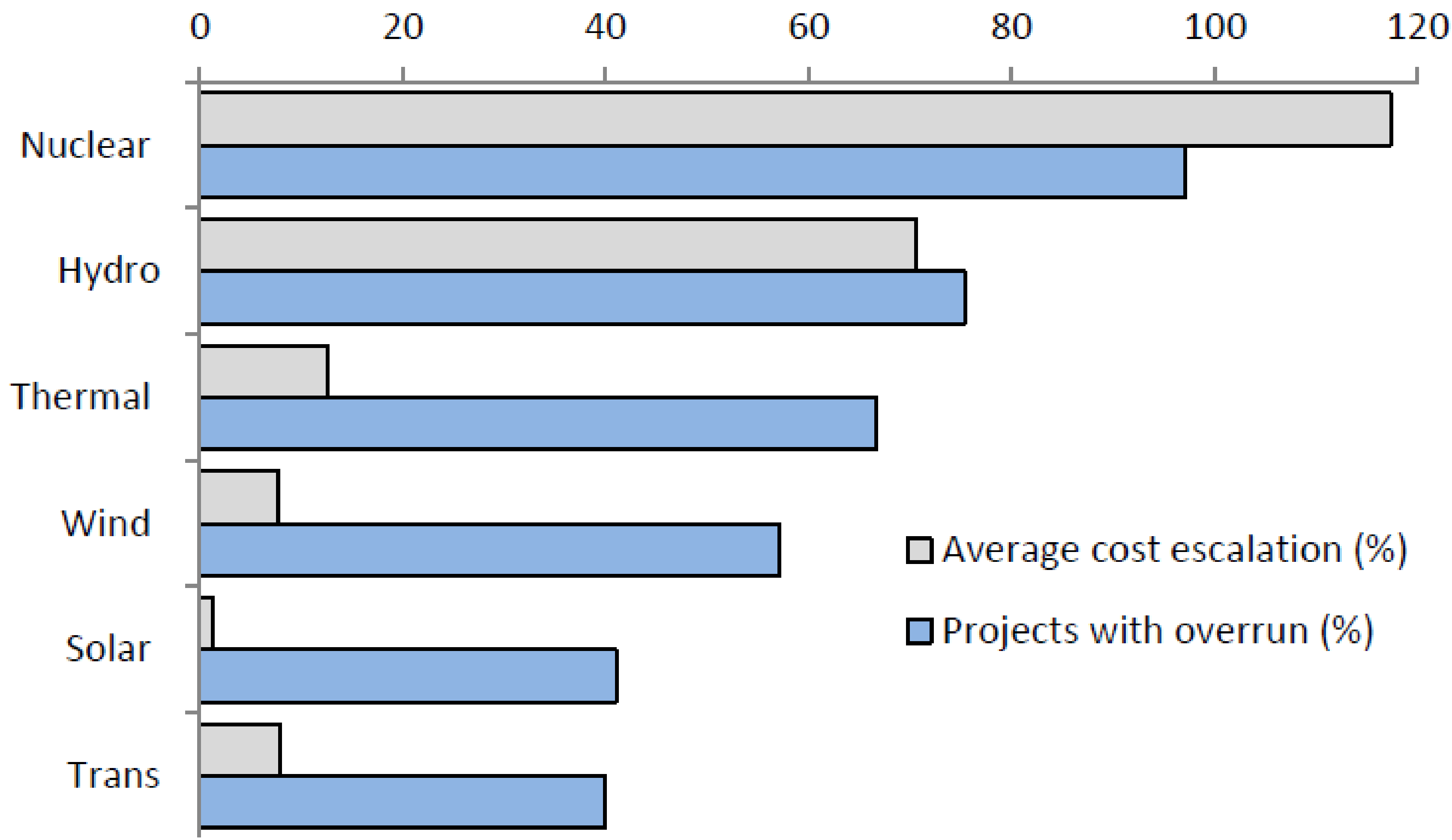

0
20
40
60
80
100
120
Nuclear
Hydro
Thermal
Wind
Solar
Trans
Average cost escalation (%)
Projects with overrun (%)

Summary of results

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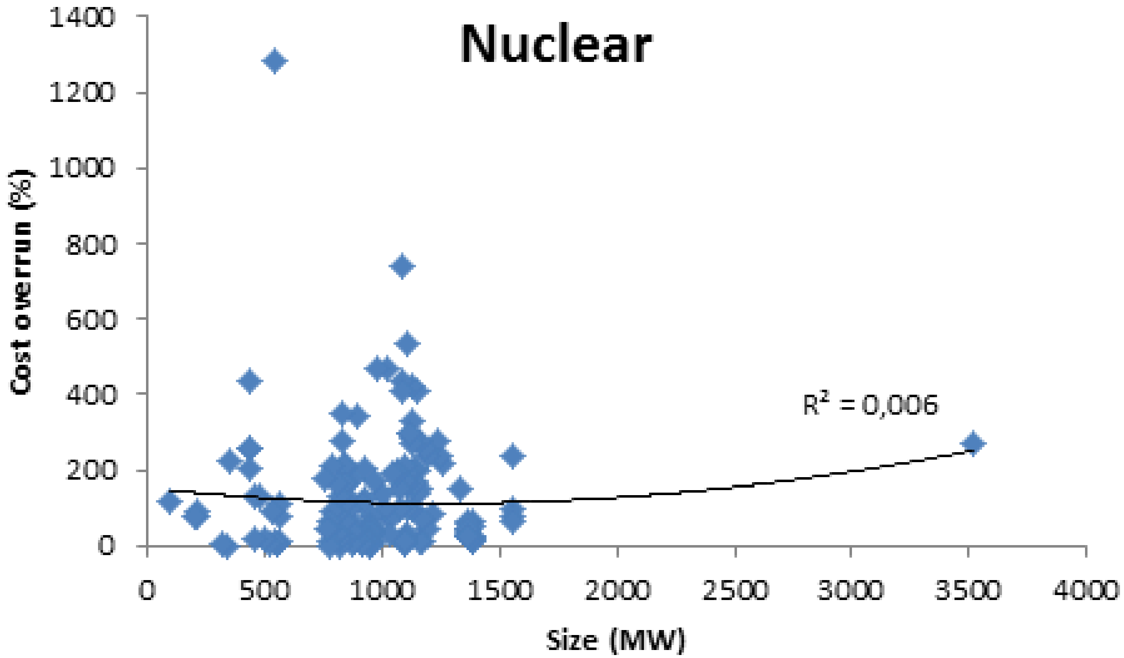
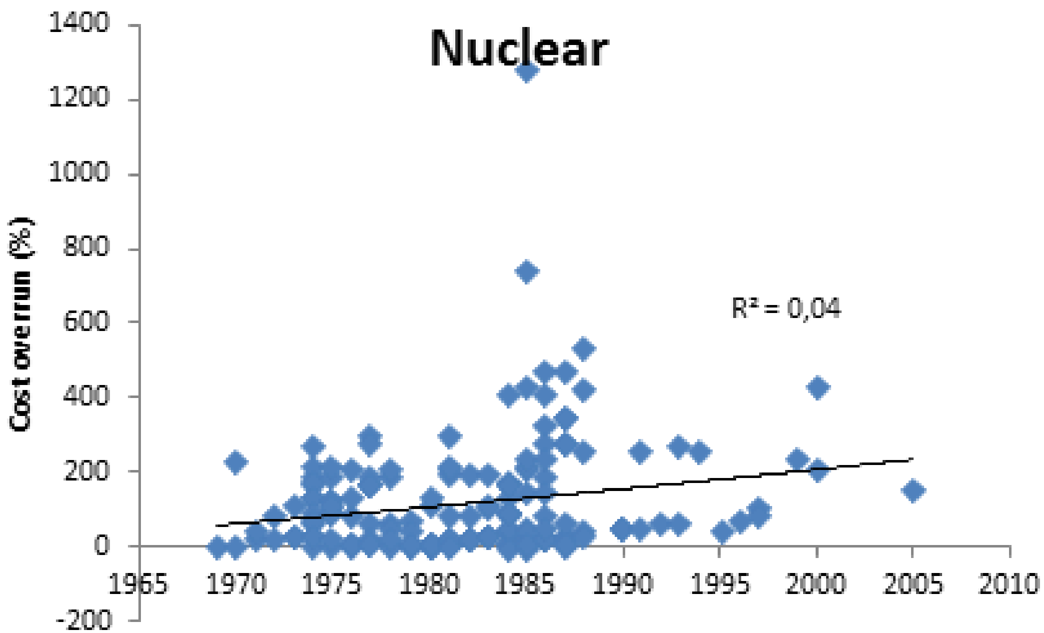
- One hundred and eighty nuclear reactors in our sample, representing 177,591 MW of installed capacity and $459 billion worth of investment, generated almost $231 billion in cost overruns (59.5 percent of all overruns across the sample), the largest of any class of technology.
- Such reactors had a mean cost escalation of 117.3 percent, and cost overruns afflicted more than nine out of every ten of the projects in our sample
- 64 percent of nuclear projects had a time overrun yet close to all of them (97.2 percent) had a cost overrun
- Contributing factors:
  - Government led promotion in the 1950s and 1960s
  - Regulatory ratcheting
  - Idiosyncrasy, at least in the United States
  - Negative learning (France)


Nuclear
Cost overrun (%)
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
2500
3000
3500
4000
Size (MW)
R² = 0,006


Nuclear
Cost overrun (%)
1400
1200
1000
800
600
400
200
0
-200
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
R² = 0,04

Our latest study

Centre on Innovation and Energy Demand

DispatchDate: 07.09.2020 · ProofNo: 696, p.1

nature energy

ANALYSIS

https://doi.org/10.1038/s41560-020-00696-3

Differences in carbon emissions reduction between countries pursuing renewable electricity versus nuclear power

Benjamin K. Sovacool[1] ✉, Patrick Schmid[2], Andy Stirling[1], Goetz Walter[2] and Gordon MacKerron[1]

Two of the most widely emphasized contenders for carbon emissions reduction in the electricity sector are nuclear power and renewable energy. While scenarios regularly question the potential impacts of adoption of various technology mixes in the future, it is less clear which technology has been associated with greater historical emission reductions. Here, we use multiple regression analyses on global datasets of national carbon emissions and renewable and nuclear electricity production across 123 countries over 25 years to examine systematically patterns in how countries variously using nuclear power and renewables contrastingly show higher or lower carbon emissions. We find that larger-scale national nuclear attachments do not tend to associate with significantly lower carbon emissions while renewables do. We also find a negative association between the scales of national nuclear and renewables attachments. This suggests nuclear and renewables attachments tend to crowd each other out.

Our latest study

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- Crucially, renewable energy strategies are, to an evidently significant degree, associated with lower levels of national carbon emissions.
- Equally salient, the climate change mitigation rationales for new nuclear investments are called into question.
- This, in turn, raises the important finding that nuclear and renewable strategies evidently tend to display such significant mutual tensions or antagonisms that one of them tends to crowd the other out.
- The implication is clear: national planners need to choose *between* nuclear power and renewables, and if they want faster and more significant carbon reductions, choose renewables

Table 1 | Correlations between research variables on carbon emissions and electricity pathways

	Nuclear countries (n = 30)			Renewable countries (n = 117)		
Timeframe 1 (1990–2004)	**(1)**	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
GDP per capita	**.52****			**.69****		
Nuclear electricity production (%)	.12	.32		**.31****	**.38****	
Renewable electricity production (%)	−.26	.08	−.30	**−.47****	−.16	**−.29****
Renewable electricity production (%), GDP per capita excluded (partial correlation)			−.34			**−.25****
Timeframe 2 (2000–2014)	**Nuclear countries (n = 30)**			**Renewable countries (n = 123)**		
	(1)	(2)	(3)	(1)	(2)	(3)
GDP per capita	**.51****			**.61****		
Nuclear electricity production (%)	−.04	.22		**.21***	**.31****	
Renewable electricity production (%)	−.23	.10	−.23	**−.38****	−.12	**−.25****
Renewable electricity production (%), GDP per capita excluded (partial correlation)			−.26			**−.22***

Notes: (1), CO_2 emissions per capita; (2), GDP per capita; (3), nuclear electricity production (%); ***$P < .001$; **$P < .01$; *$P < .05$.

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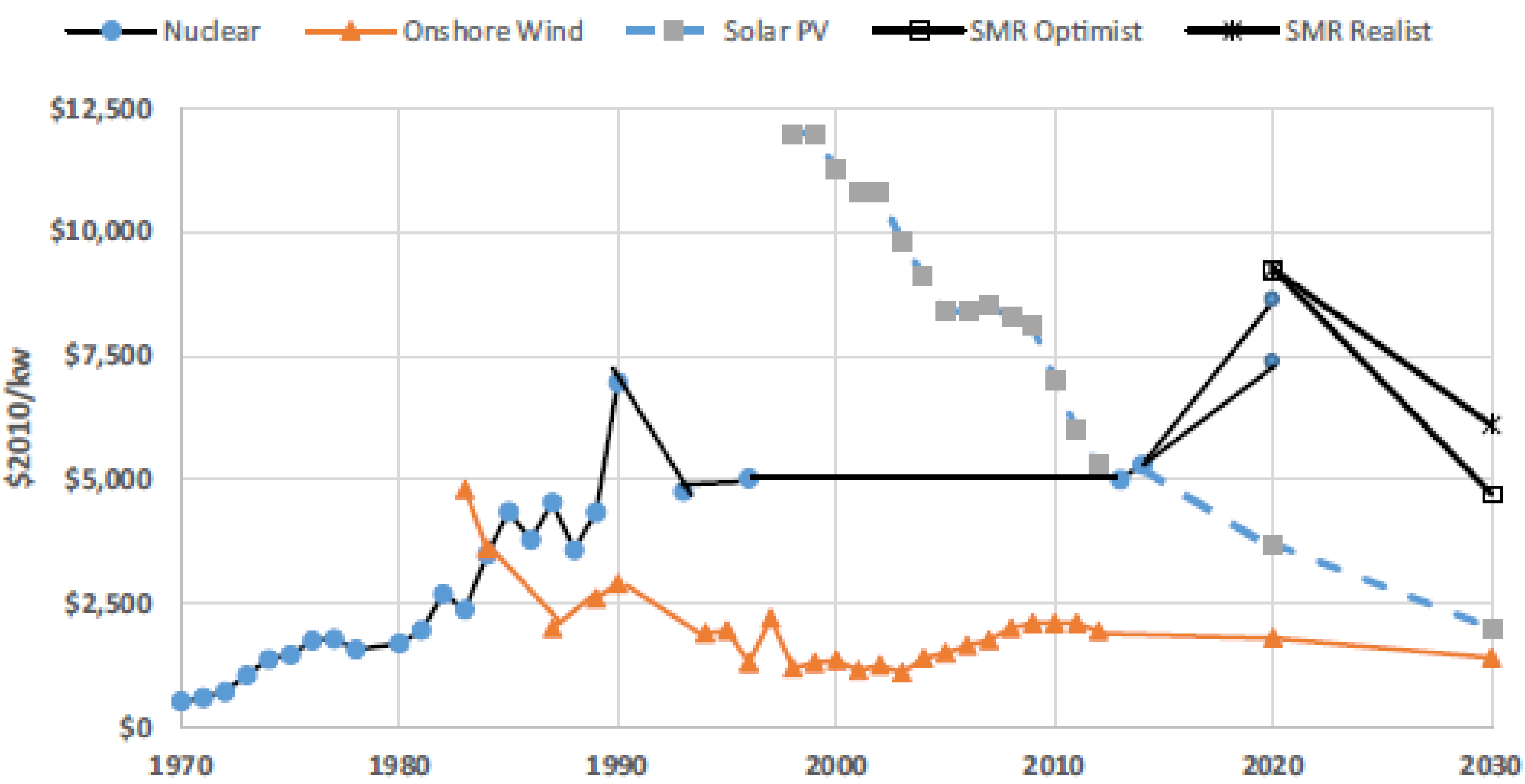
Review

Small modular reactors and the future of nuclear power in the United States

Mark Cooper *



Nuclear
Onshore Wind
Solar PV
SMR Optimist
SMR Realist
$12,500
$10,000
$7,500
$5,000
$2,500
$0
$2010/kw
1970
1980
1990
2000
2010
2020
2030

Conclusions

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- Nuclear energy is not “carbon free,” but it is legitimately low-carbon
  - Perhaps dirtier than its advocates proclaim, cleaner than its critics state
  - Carbon footprint will change over time, most likely for the worse
- Nuclear energy will almost always cost more than you expect to build, even if it performs well afterwards
- Nuclear energy has incredibly long lead times, so it takes longer to mitigate emissions than more modular technologies
- It is troubling we cannot confirm the “nuclear countries” hypothesis in our most recent study
- SMRs may be too distant and costly to mitigate carbon as well

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