1.2.1.008 - Value Drivers Quantification

Todd Levin
Argonne National Laboratory

tlevin@anl.gov

July 27, 2022

Project Overview

Project Summary

We develop a rigorous, quantitative framework that quantifies the relative impact of different system-level value drivers for hydropower resources by:

1. Analyzing historical electricity market data to identify system factors that have influenced energy prices.
2. Executing production cost models to simulate electricity prices under different system conditions.
3. Applying a custom statistical calibration tool to adjust modeled price distributions to account for system uncertainty.
4. Applying a hydropower management tool to optimize plant operations in response to price signals and determine the system value provided by hydropower under different system conditions.

Intended Outcomes

- A framework for value driver quantification that and broadly applicable across the U.S. for various system conditions.
- An application of this framework across several regional case studies to identify the system- and plant-level drivers of hydropower value.

Project Information

Principal Investigator(s)

- **ANL** - Todd Levin, Zhi Zhou, Siby Plathottam, Matt Mahalik, Tom Veselka, Jonghwan Kwon, Quentin Ploussard

Project Partners/Subs

- **PNNL** - Abhishek Somani, Konstantinos Oikonomou, Nader Samaan, Sohom Datta
  NREL - Greg Stark, Greg Brinkman

Project Status

Sunsetting

Project Duration

- October 1, 2020
- September 30, 2022

Total Costed (FY19–FY21)

$776k

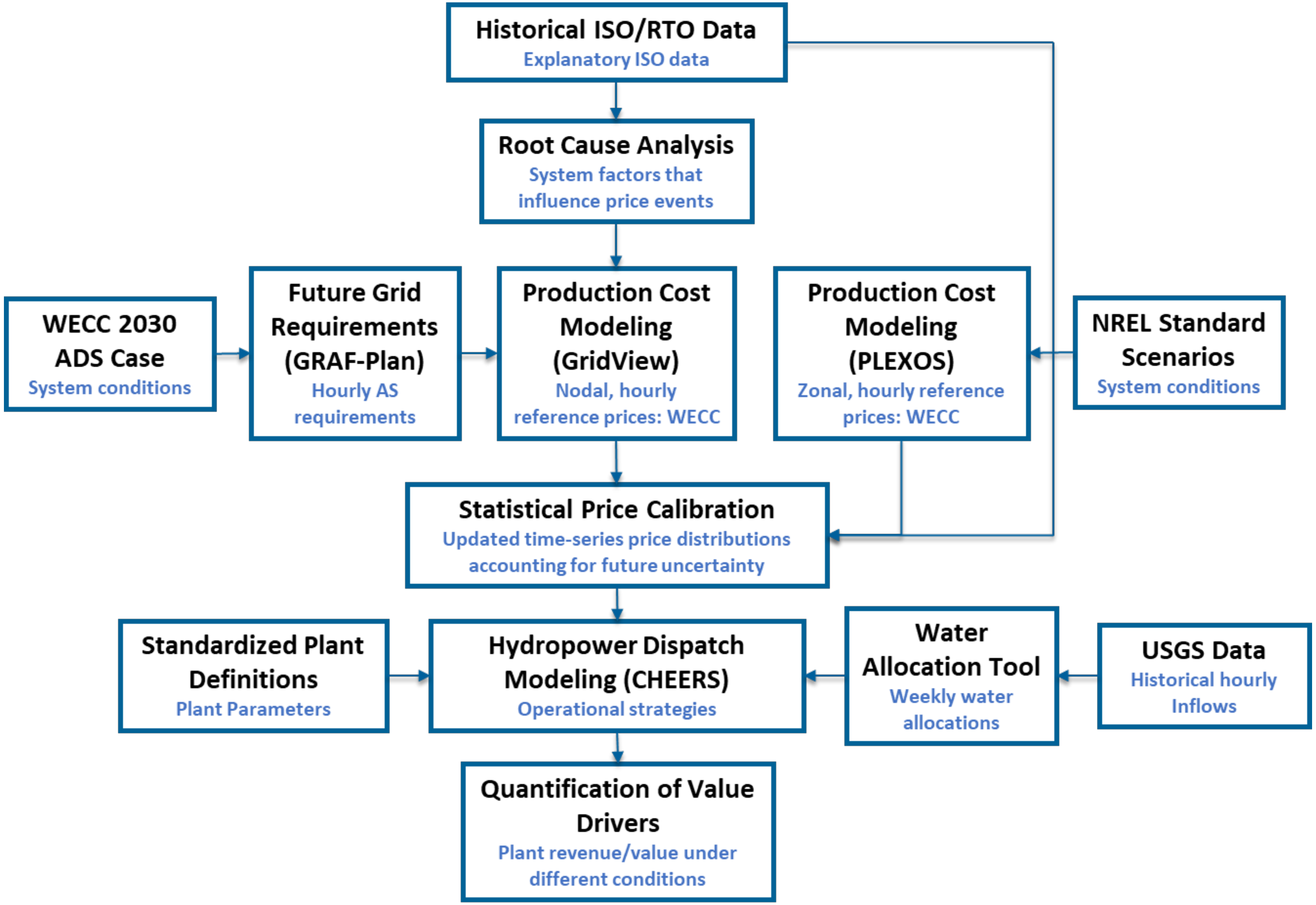
Project Objectives: Relevance

Relevance to Program Goals:

This project contributes to WPTO's mission of enabling research, development, testing and commercialization of new technologies to advance the next-generation hydropower and pumped storage systems for a flexible, reliable grid. Specifically, the project supports the following hydropower program goals and objectives stated in the WPTO Multi-Year Program Plan:

- **Challenge:** Untapped potential for hydro and pumped storage to support a rapidly evolving grid
- **Approaches and activities:** Understand the evolving needs of the rapidly changing grid, Optimize hydropower operations and planning—alongside other
- resources—to best utilize hydropower's capabilities
- **Intermediate outcomes:** Accurate representation and system value of hydropower and
- PSH capabilities in power system models
- **Long-term outcomes:** Increase U.S. hydropower and PSH fleet flexibility and provide greater value to the power system

Project Objectives: Approach



Project Objectives: Expected Outputs and Intended Outcomes

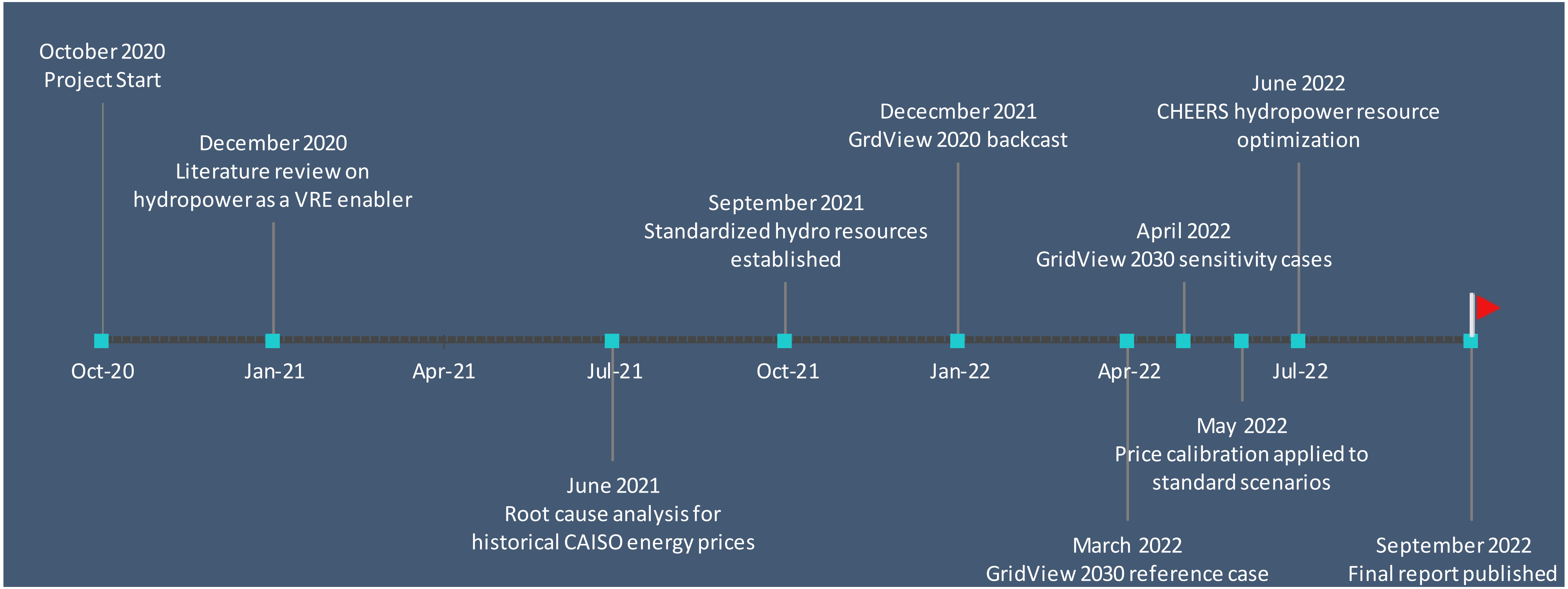
Outputs:

- Framework for hydropower value quantification
- GridView
  - WECC 2030 ADS enhancements
  - WECC 2020 backcast model
- New weekly water allocation tool
- Technical report summarizing:
  - Framework and technical methodologies
  - Key hydropower value drivers identified from case study applications of the framework
  - Comprehensive review of literature on system value drivers

Outcomes:

- Quantify the relative impacts of different hydropower value drivers, increasing stakeholder awareness of how hydropower operations may evolve in future power systems
- Identify market enhancements that may be needed to recognize the value that hydropower can provide in evolving power systems

Project Timeline



Quarterly review meetings were also held with an industry technical advisory group

Project Budget

Total Project Budget – Award Information		
DOE	**Cost-share**	**Total**
$1300K	0$K	$1300K

FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	**Costed**	**Costed**	**Total Costed**
$0K	$0K	$776k	776K

- Project is on track to be completed by the end of FY22

End-User Engagement and Dissemination

- This work will benefit stakeholders with an interest in improving or adjusting hydropower operational strategies to leverage evolving value streams and increase value that these resource provide to the system under different conditions. Including:
- This work may also benefit a broader audience of stakeholders with a vested interest in understanding how prices for energy and ancillary services may evolve under different future system conditions, such as:
- We engaged with a Technical Advisory Group quarterly to present progress and findings and solicit feedback
  - This process helps to ensures that our work is relevant to industry stakeholders
- Project results will be disseminated through:
  - HydroWIRES Technical Report
  - Journal articles
  - Conference presentations

Primary Beneficiaries

- The hydropower industry
- PMAs
- Regulators
- Utilities

Additional Beneficiaries

- Developers
- Grid operators
- Researchers
- DOE program offices

Technical Advisory Group

- Rebecca Johnson (WAPA)
- Rahul Kalaskar (CAISO)
- Clint Kalich (Avista Energy)
- Shane Messano (WAPA)
- Patrick O'Connor (Duke Energy)
- Cameron Schilling (NHA)

Key hydropower value drivers identified

Calculated hydropower value ($/kW-year) for 245 scenarios

Total Value ($/kW-year)

	Price Scenario	Reference	Fast ramp	Slow ramp	High storage	Low storage	High water	Low water
BPA	Reference	172	202	165	179	163	205	128
	Wet Hydro	175	204	168	181	170	205	
	Dry Hydro	181	210	174	190	174		128
	High Electrification	172	198	164	181	168	203	116
	High Gas Price	186	214	179	194	175	232	124
	Coal Repower 30%	192	220	185	198	184	222	151
	Coal Repower 100%	120	148	114	125	108	145	80
	Coal Repower 100% LDES	121	150	114	128	109	144	83
	Coal Repower 100% High AS	136	199	121	143	123	161	92
WAPA	Reference	144	173	137	148	150	182	103
	Wet Hydro	143	173	136	146	146	179	
	Dry Hydro	146	174	139	150	153		101
	High Electrification	142	167	134	142	155	183	90
	High Gas Price	166	192	159	168	174	219	109
	Coal Repower 30%	142	167	135	142	144	171	103
	Coal Repower 100%	103	127	98	107	109	124	79
	Coal Repower 100% LDES	103	129	97	106	105	122	75
	Coal Repower 100% High AS	119	178	106	122	122	140	84
NY	Cambium Reference	108	120	104	120	102	135	63
	Cambium High VRE	85	95	82	93	79	104	55
	Cambium High VRE High AS	92	113	85	99	86	111	60
TVA	Cambium Reference	83	91	80	94	77	111	58
	Cambium High VRE	80	88	77	96	73	105	57
	Cambium High VRE High AS	85	103	80	102	79	111	62

Reservoir

Total Value ($/kW-year)

	Price Scenario	Storage Capacity	No AS	10% AS	20% AS
California	Reference	5 Hours	72	78	85
		10 Hours	75	81	89
		20 Hours	76	82	89
	Wet Hydro	5 Hours	80	85	93
		10 Hours	84	90	97
		20 Hours	85	90	98
	Dry Hydro	5 Hours	67	73	80
		10 Hours	69	75	82
		20 Hours	70	75	82
	High Electrification	5 Hours	74	80	87
		10 Hours	76	81	89
		20 Hours	76	81	89
	High Gas Price	5 Hours	77	82	89
		10 Hours	81	87	94
		20 Hours	82	87	94
	Coal Repower 30%	5 Hours	81	87	94
		10 Hours	86	92	99
		20 Hours	87	92	100
	Coal Repower 100%	5 Hours	83	89	96
		10 Hours	91	96	103
		20 Hours	92	97	104
	Coal Repower 100% LDES	5 Hours	84	90	97
		10 Hours	90	96	103
		20 Hours	91	97	104
	Coal Repower 100% High AS	5 Hours	83	97	114
		10 Hours	91	104	121
		20 Hours	92	105	122

PSH

Key hydropower value drivers identified

Normalized relative value

Region Normalized Total Value

	Price Scenario	Reference	Fast ramp	Slow ramp	High storage	Low storage	High water	Low water
BPA	Reference	100%	118%	96%	104%	95%	119%	75%
	Wet Hydro	102%	119%	98%	106%	99%	119%	
	Dry Hydro	105%	122%	101%	111%	101%		75%
	High Electrification	100%	115%	96%	105%	98%	118%	67%
	High Gas Price	108%	125%	105%	113%	102%	135%	72%
	Coal Repower 30%	112%	128%	108%	115%	107%	129%	88%
	Coal Repower 100%	70%	86%	66%	73%	63%	84%	46%
	Coal Repower 100% LDES	70%	88%	66%	75%	63%	84%	48%
	Coal Repower 100% High AS	79%	116%	71%	83%	72%	94%	54%
WAPA	Reference	100%	120%	95%	103%	104%	126%	71%
	Wet Hydro	99%	120%	94%	101%	101%	124%	
	Dry Hydro	101%	120%	96%	104%	106%		70%
	High Electrification	98%	116%	93%	98%	107%	127%	62%
	High Gas Price	115%	133%	110%	116%	120%	151%	75%
	Coal Repower 30%	98%	116%	94%	99%	100%	118%	71%
	Coal Repower 100%	72%	88%	68%	74%	75%	86%	55%
	Coal Repower 100% LDES	71%	90%	67%	73%	73%	84%	52%
	Coal Repower 100% High AS	82%	123%	74%	85%	85%	97%	58%
NY	Cambium Reference	100%	111%	96%	111%	95%	125%	59%
	Cambium High VRE	78%	88%	75%	86%	73%	96%	51%
	Cambium High VRE High AS	85%	104%	79%	92%	79%	103%	55%
TVA	Cambium Reference	100%	110%	97%	113%	93%	134%	69%
	Cambium High VRE	96%	107%	92%	115%	89%	126%	68%
	Cambium High VRE High AS	103%	124%	96%	124%	95%	134%	74%

Reservoir

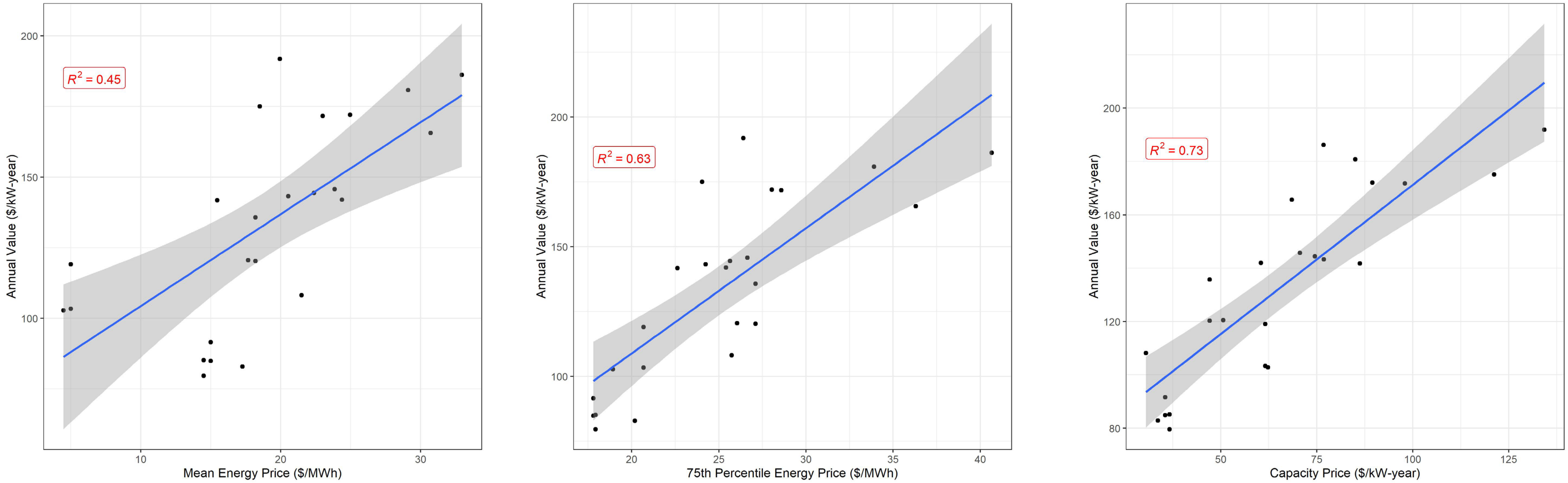
Scenario Normalized Value (%)

	Price Scenario	Storage Capacity	No AS	10% AS	20% AS
California	Reference	5 Hours	89%	96%	105%
		10 Hours	93%	100%	109%
		20 Hours	94%	101%	110%
	Wet Hydro	5 Hours	88%	95%	103%
		10 Hours	94%	100%	108%
		20 Hours	94%	101%	109%
	Dry Hydro	5 Hours	89%	97%	107%
		10 Hours	92%	100%	110%
		20 Hours	93%	101%	110%
	High Electrification	5 Hours	91%	98%	107%
		10 Hours	93%	100%	109%
		20 Hours	93%	100%	109%
	High Gas Price	5 Hours	89%	95%	103%
		10 Hours	94%	100%	108%
		20 Hours	95%	101%	109%
	Coal Repower 30%	5 Hours	88%	94%	102%
		10 Hours	94%	100%	108%
		20 Hours	94%	101%	108%
	Coal Repower 100%	5 Hours	87%	92%	100%
		10 Hours	94%	100%	107%
		20 Hours	95%	101%	108%
	Coal Repower 100% LDES	5 Hours	88%	94%	101%
		10 Hours	94%	100%	107%
		20 Hours	95%	101%	108%
	Coal Repower 100% High AS	5 Hours	80%	93%	109%
		10 Hours	87%	100%	116%
		20 Hours	88%	101%	117%

PSH

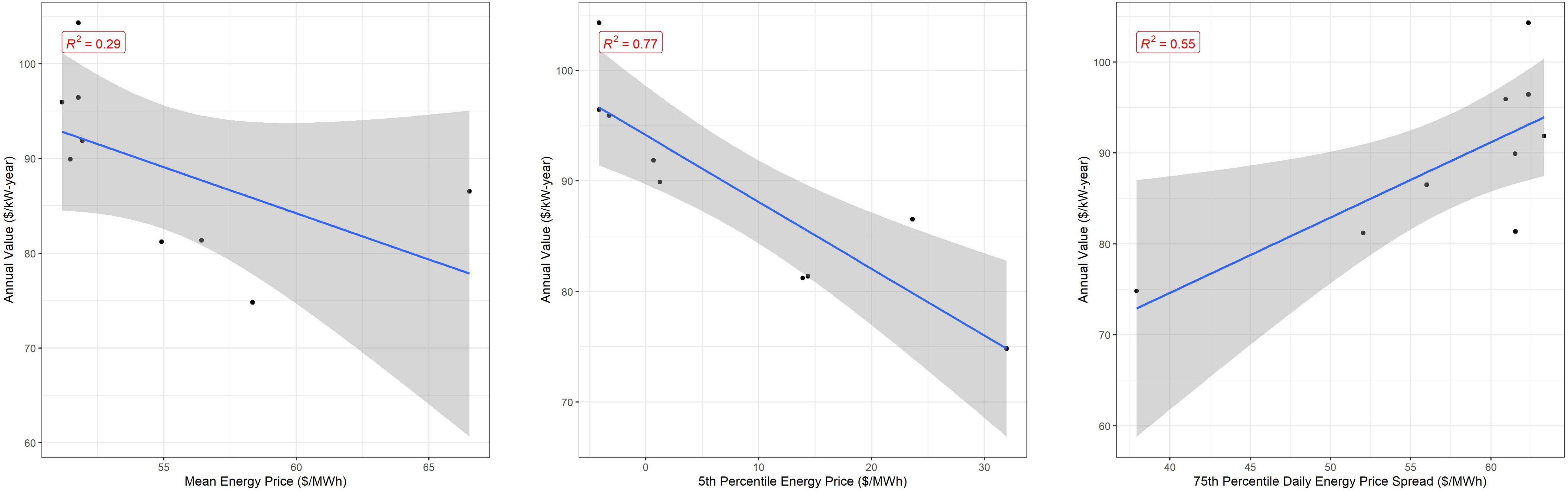
Impact of Energy Price: Reservoir

- Mean energy price is not the strongest determinant of **reservoir** value
  - Stronger correlation with the 75th percentile of energy price
- Capacity price is also strongly correlated



Impact of Energy Price: PSH

- Mean energy price is not the strongest determinant of PSH value
  - Stronger correlation with
    - 5th percentile of energy price
    - 75th percentile of daily price spread (max price – min price)



Other Key Drivers

Other key value drivers: Water availability, plant flexibility, mean reg-up price

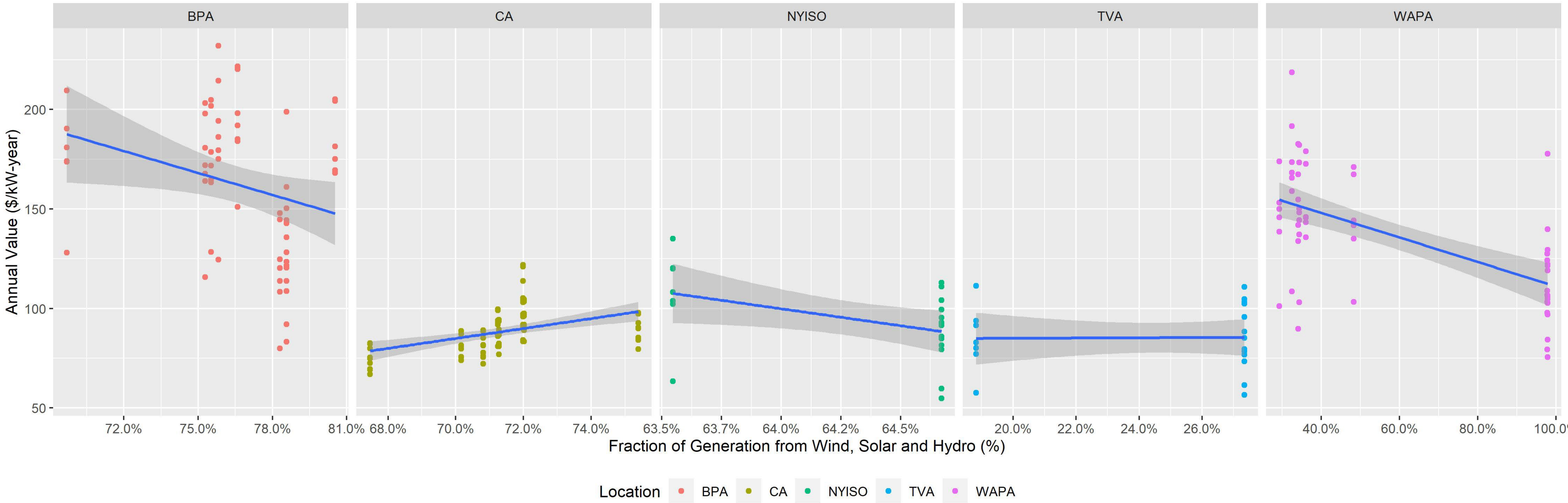
- Collectively explain 91% of variation in value
- Storage capacity not as strong of a driver

Reservoir Value

	Dependent variable:					
	Annual Value					
	(1)	(2)	(3)	(4)	(5)	(6)
Energy 75th Percentile	4.700***	4.822***	3.207***	3.267***	3.267***	3.266***
	(0.427)	(0.355)	(0.232)	(0.227)	(0.182)	(0.180)
Annual Water (AF)		0.0001***	0.0001***	0.0001***	0.0001***	0.0001***
		(0.00001)	(0.00001)	(0.00001)	(0.00000)	(0.00000)
Capacity Price			0.856***	0.868***	0.868***	0.868***
			(0.050)	(0.049)	(0.039)	(0.039)
Ramp Rate (indicator)				1.489***	1.489***	1.488***
				(0.481)	(0.385)	(0.382)
Mean Reg-up Price					16.776***	16.776***
					(1.770)	(1.756)
Storage Capacity (indicator)						3.324*
						(1.757)
Constant	17.200	-62.239***	-75.859***	-90.557***	-90.557***	-90.199***
	(10.948)	(12.938)	(7.774)	(8.939)	(7.160)	(7.105)
Observations	164	164	164	164	164	164
R^2	0.428	0.608	0.861	0.869	0.916	0.918
Adjusted R^2	0.424	0.604	0.858	0.866	0.914	0.915
Residual Std. Error	31.691 (df = 162)	26.293 (df = 161)	15.715 (df = 160)	15.310 (df = 159)	12.263 (df = 158)	12.164 (df = 157)
F Statistic	121.020*** (df = 1; 162)	125.074*** (df = 2; 161)	330.327*** (df = 3; 160)	263.419*** (df = 4; 159)	346.439*** (df = 5; 158)	294.004*** (df = 6; 157)
Note:						*p<0.1; **p<0.05; ***p<0.01

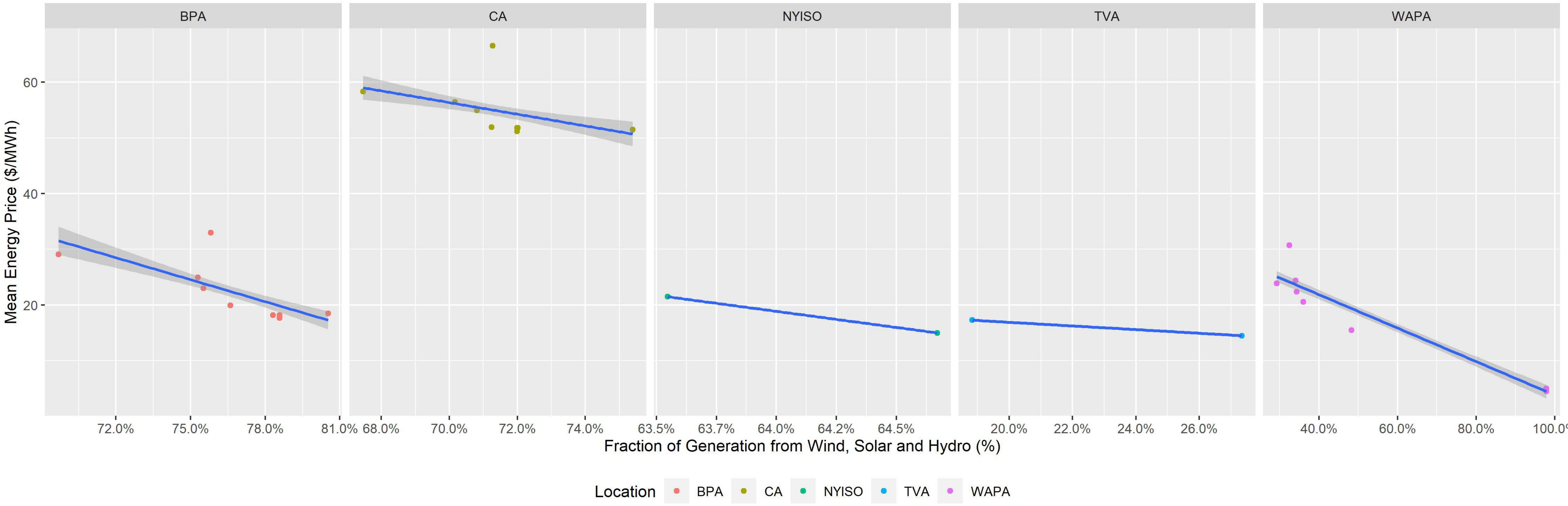
Impact of VRE

- Reservoir hydropower value generally decreases with higher VRE
- PSH value increases



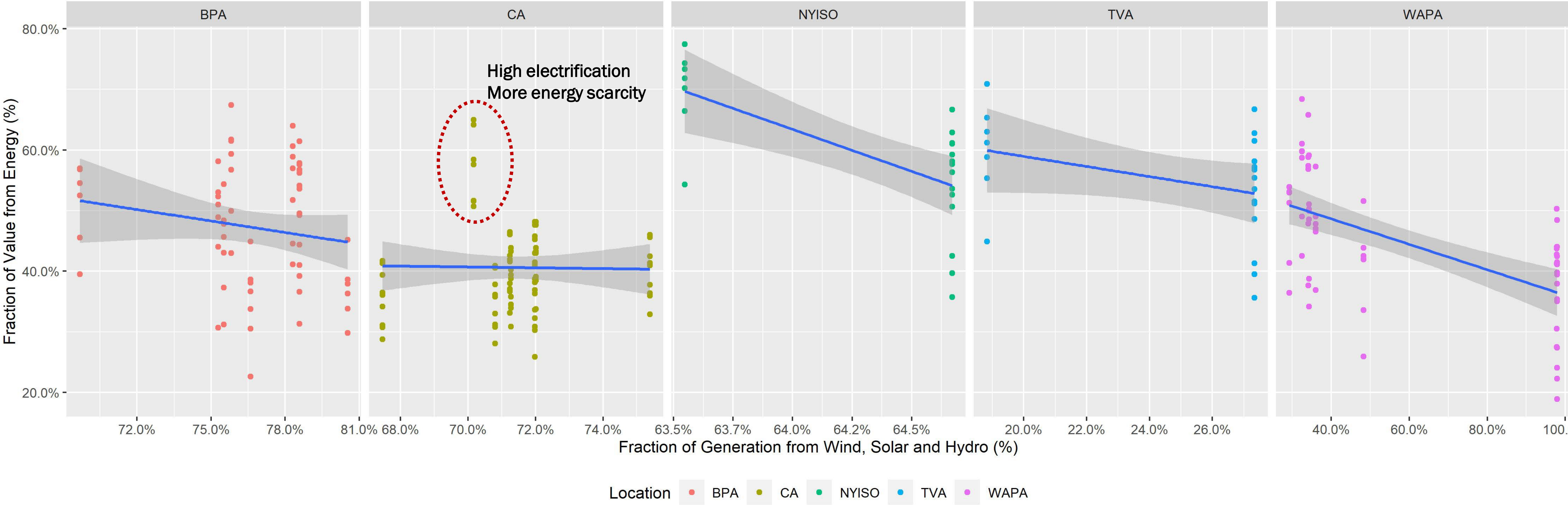
Impact of VRE

- This is consistent with energy price trends



Impact of VRE

- Share of value from energy decreases
  - Shares from capacity and ancillary services increase



Key Market Design Considerations

- Increased capacity and ancillary service revenues do not full replace lost energy revenues in high VRE futures

- Market and planning enhancements may be required to ensure that the services hydropower provides are appropriately valued and compensated

- Model enhancements are also needed to better understand future capacity and ancillary service valuation trends

Planned Publications

- Journal Articles
  - *"Root cause analysis of wholesale electricity prices"*
    - In preparation
  - *"Data-driven electricity price calibration based on Bayesian Inference"*
    - In preparation
  - *"Production cost model enhancement through back cast validation"*
    - In preparation
- Technical Reports
  - *"Hydropower Value Drivers"*
    - In preparation

Q&A