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# Technology Portfolio

Сравнение предположений о стоимости технологии в  
моделях комплексной оценки MESSAGE и GCAM

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# Objective:

## цель:

- **Characterizing the main power generation technologies**
- охарактеризовать основные технологии производства электроэнергии
- **Creating transparency for the Pathways project**
- Создание прозрачности для проекта Pathways
  - Detailing the techno-economic input assumptions (CapEx, O&M, Efficiency, Lifetime)  
Предоставить информацию по технико-экономическим обоснованиям  
(капитальные затраты, стоимость эксплуатации и обслуживания, техническая эффективность, технический срок службы)
  - Comparing the models with each other and with literature values  
Сравнение моделей друг с другом и с литературными данными
  - Displaying annualized cost for each technology to consider all factors simultaneously (CapEx, O&M and Lifetime)
  - Отображение годовой стоимости каждой технологии

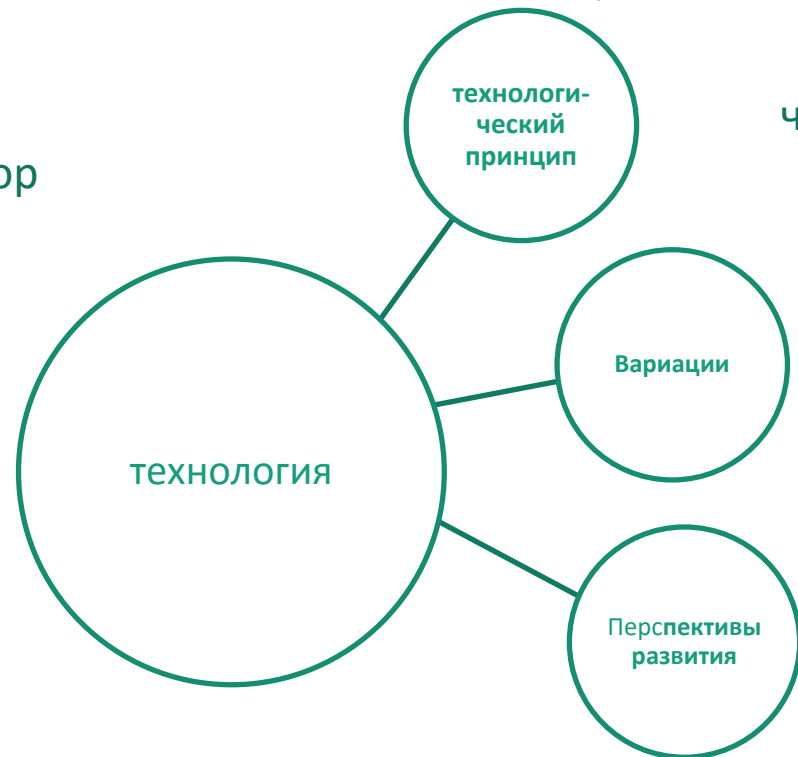
# Activities: Technology Description

## действия: Описание технологии

- Descriptions of each technology reader with a brief overview the report):
- Описания каждой технологии, предоставить читателю краткий обзор

to provide  
(details are in

чтобы



# Activities: Technology Description

## действия: Описание технологии

### включены описания технологий:

- Renewable technologies **Возобновляемые** :
  - Photovoltaics **фотоэлектрические системы**
  - Concentrated solar power **технологии по концентрации солнечной энергии**
  - Wind power **ветроэнергетика**
  - Hydro power **Гидроэнергетика**
  - Biomass **биомасса**

# Activities: Technology Description

## действия: Описание технологии

### включены описания технологий:

- Conventional technologies **обычные электростанции** :

- Coal-fueled power plants

**Электростанции на угольном топливе**

(IGCC, subcritical, supercritical)

**Комплексная установка для  
комбинированного цикла газа (IGCC),  
оборудования на до-, сверх- и  
суперсверхкритические параметры пара**

- Gas combustion

**Электростанция на газовом топливе**

(CCGT, gas steam power)

**Парогазовая установка**

- Nuclear power

**Ядерная энергия**

# Activities: Data Comparison

## действия: сравнение данных



# Activities: Data Comparison

## действия: сравнение данных

### Literature Comparison сравнение литературных данных

- Values from open literature
- Studies including parameters for the time period from 2010 to 2050 were prioritized
- данные из открытой литературы
- исследования, включая параметры для периода времени 2010-2050 были приоритетными

### Visualization визуализация

- Literature values were cumulated into cost ranges
- Overlapping ranges with darker grey shade
- Model assumptions were added on top of the literature ranges
- Литературные данные были объединены в стоимостные диапазоны
- места перекрытия (темно-серый)
- Предположения модели были добавлены в дополнение к литературным диапазонам

### Adding Annualized Cost добавление годовой СТОИМОСТИ

- Complementing the direct comparison of capital cost, O&M cost and efficiencies
- This approach allowed a comparison that takes into account both cost factors and lifetime
- Дополняя прямое сравнение входных параметров
- Такой подход позволяет рассчитывать как затраты, так и срок службы

# Activities: Data Comparison

## действия: сравнение данных

### Adding Annualized Cost добавление годовой СТОИМОСТИ

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- AC calculated once without interest rates and once with interest rates
- Годовая стоимость (AC) рассчитывается один раз без процентных ставок и один раз с процентными ставками
  - The calculation including interest rates has been conducted with the following formulae:
  - Расчет выполнен со следующей формулой:
- Calculation of the Annuity factor:  $A(t, r) = \frac{1 - (1/(1+r)^t)}{r}$ 

t = lifetime техн. срок лужбы  
r = interest rate процентная ставка
- Calculation of annualized cost:  $AC = \frac{\text{Capital cost}}{A(t, r)} + O\&M \text{ cost}$



# GCAM/MESSAGE Discount rates

## Дисконтные ставки

- GCAM and MESSAGE use different methods to annualize their CapEx for technology cost calculations
- GCAM и MESSAGE используют разные методы для расчета для расчета годовой стоимости технологии
- GCAM uses a Fixed Charge Rate (**13%**), which includes multiple discounting factors such as: depreciation, interest rate, taxes and return on equity
- GCAM использует фиксированную ставку (13%), которая включает коэфф. дисконтирования: амортизация, процентная ставка, налоги, рентабельность капитала
- MESSAGE uses the interest rate to discount investment costs over lifetime of the technology (**5%**). Other mentioned factors are considered at different stages
- модель использует процентную ставку для снижения инвестиционных затрат за весь срок службы технологии (5%). Другие упомянутые факторы рассматриваются на других этапах
- **Differences in calculated ann. cost due to different methodologies**
- различия в годовой стоимости технологии из-за разных методов моделирования

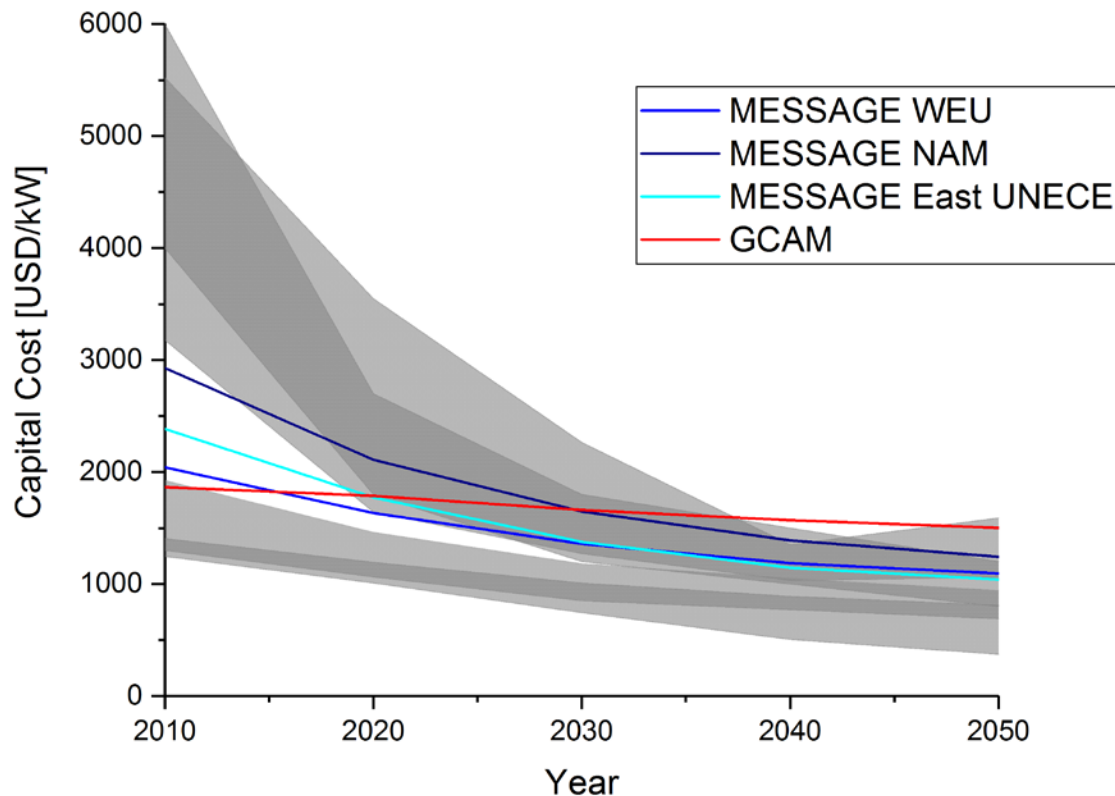
# Results – Example Renewable: Solar PV

## результаты - Пример Возобновляемые источники энергии: Солнечная фотогальваника

- **Capital Cost**

- **Капитальные затраты**

- General trend among models and literature is similar
- Общая тенденция среди моделей и литературы аналогична
- GCAM more conservative, smaller overall cost decline
- общее снижение стоимости меньше в модели GCAM
- MESSAGE with similar developer for all regions
- аналогичное развитие для всех регионов в модели MESSAGE

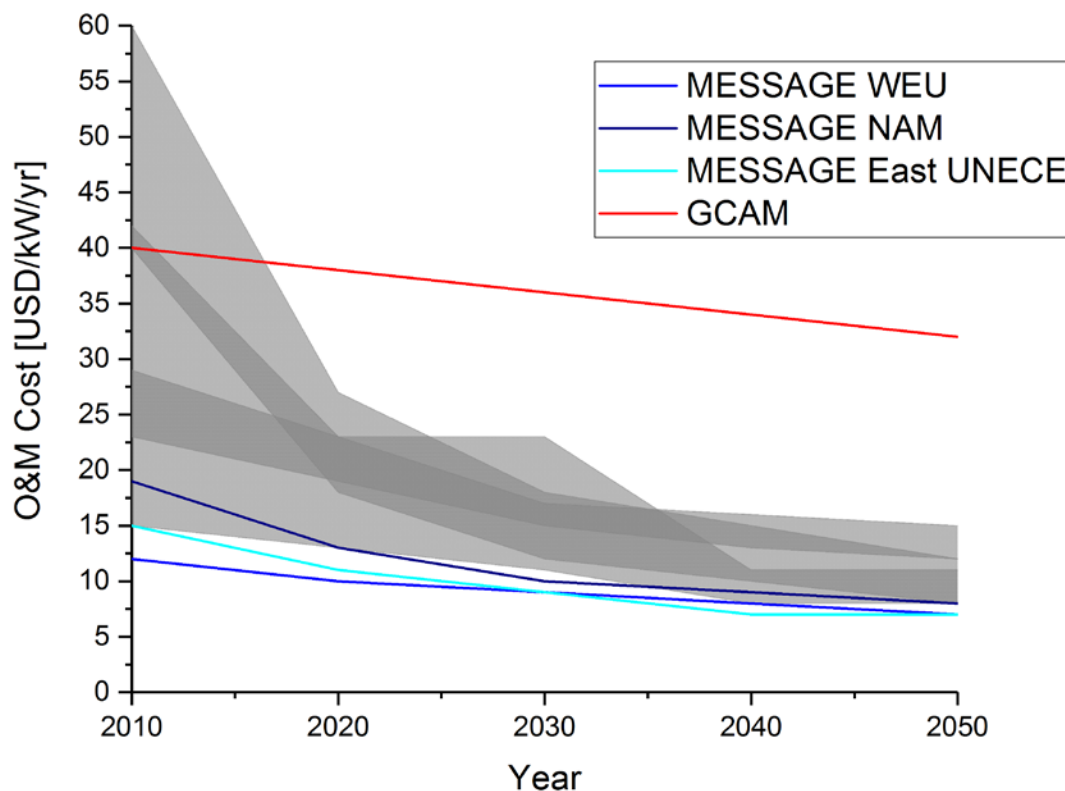


Comparison of literature values (grey area) and the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)

# Results – Example Renewable: Solar PV

## результаты - Пример Возобновляемые источники энергии: Солнечная фотогальваника

- **Operation and Maintenance Cost**
- **СТОИМОСТЬ эксплуатации и обслуживания**
  - Greater difference between MESSAGE and GCAM
  - GCAM more than 100% higher than MESSAGE
  - разница между моделями
  - предположения более чем на 100% выше в GCAM

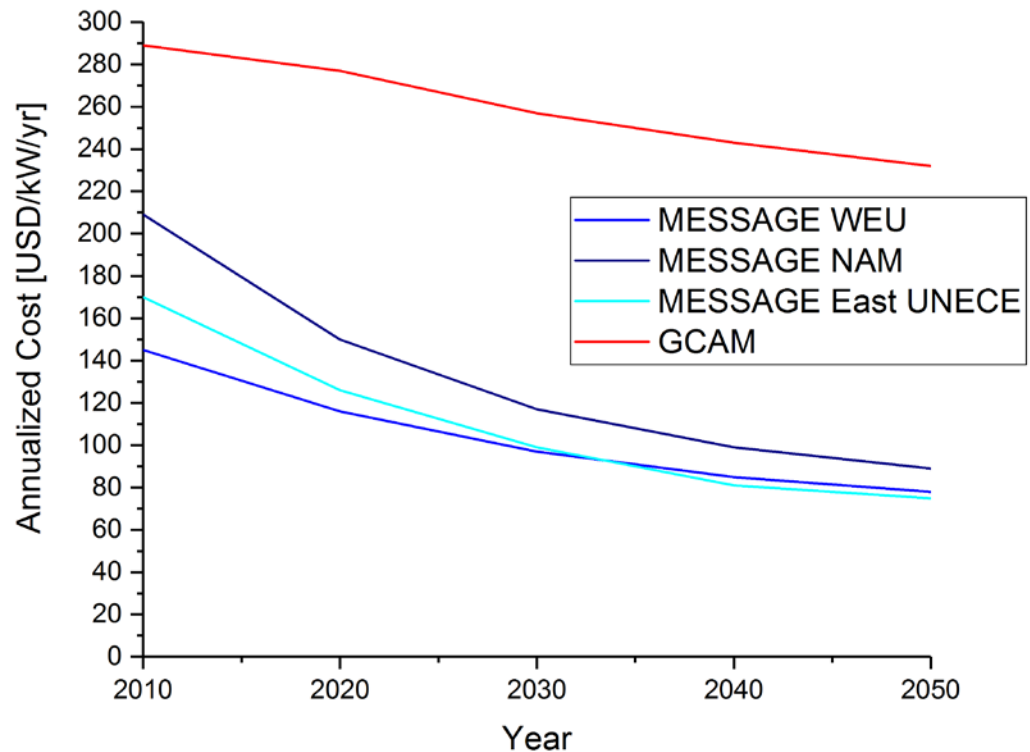


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# Results – Example Renewable: Solar PV

## результаты - Пример Возобновляемые источники энергии: Солнечная фотогальваника

- Annualized Cost with interest rates
- годовая стоимость с процентными ставками
- процентные ставки:
  - MESSAGE 5%
  - GCAM 13%
- Large difference in discount rates pulls GCAM and MESSAGE further apart

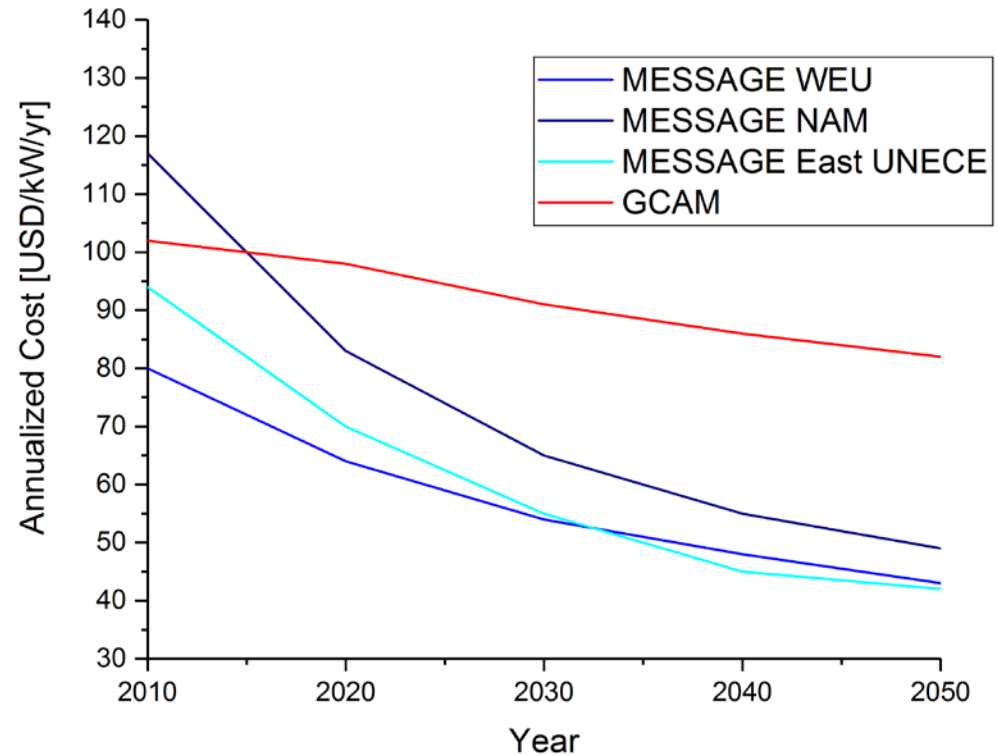


Comparison the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)

# Results – Example Renewable: Solar PV

## результаты - Пример возобновляемые источники энергии: Солнечная фотогальваника

- Annualized Cost without interest rates
- годовая стоимость без процентных ставок
  - Not including interest rates brings GCAM and MESSAGE closer together
  - Main difference because of high O&M cost in GCAM
  - Без учета процентных ставок GCAM и MESSAGE сближаются
  - Основное различие из-за высокой стоимости производственных и эксплуатационных расходов в GCAM



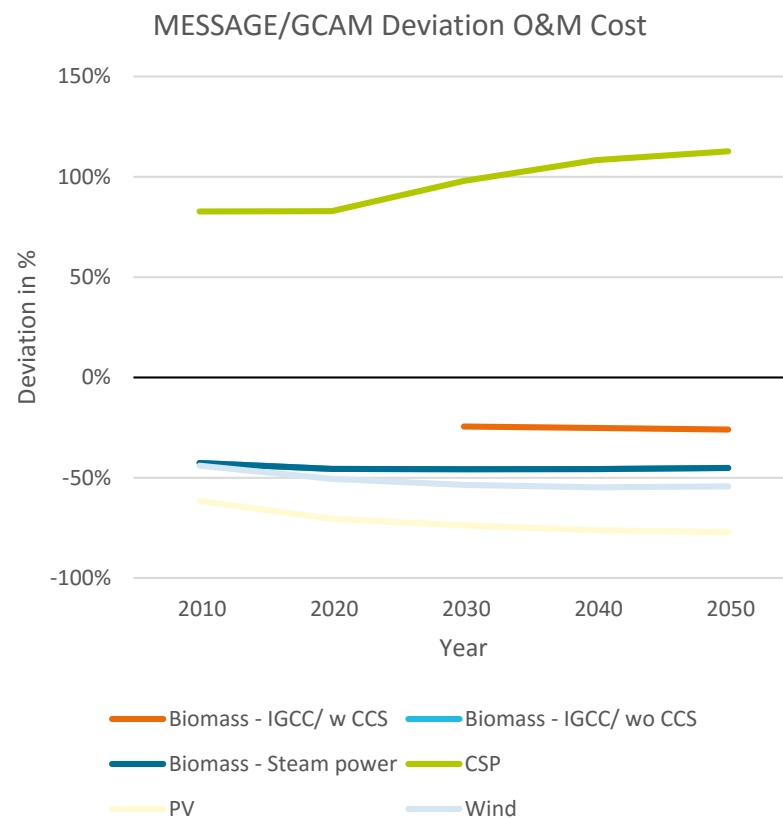
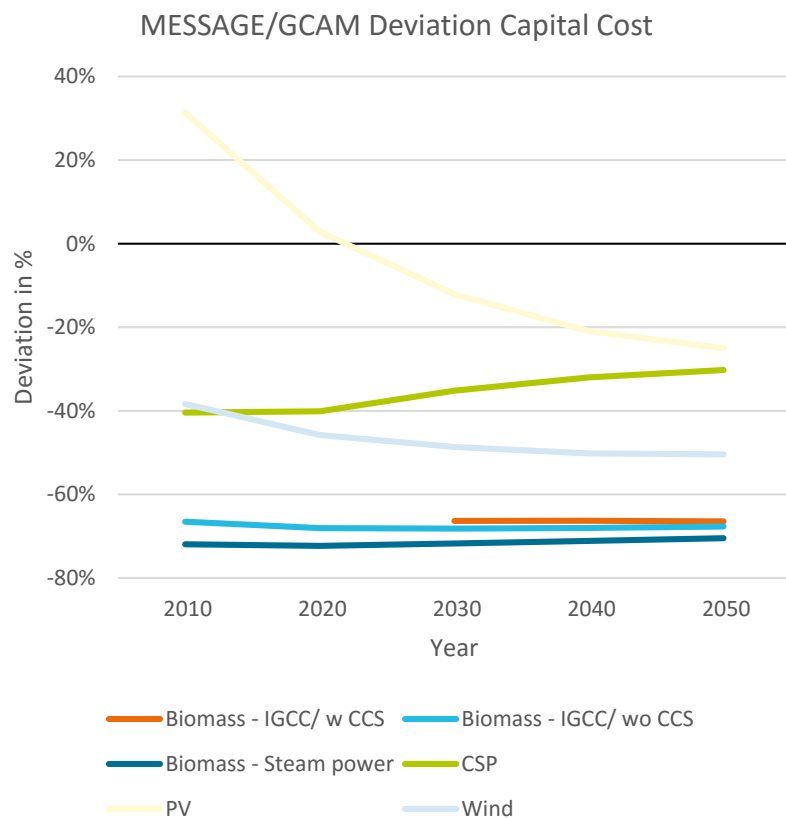
Comparison the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)

# Summary: Deviation between GCAM and MESSAGE

## резюме – девиация между моделями GCAM и MESSAGE

Renewable power generation technologies – comparison of the deviation of capital and O&M cost over time

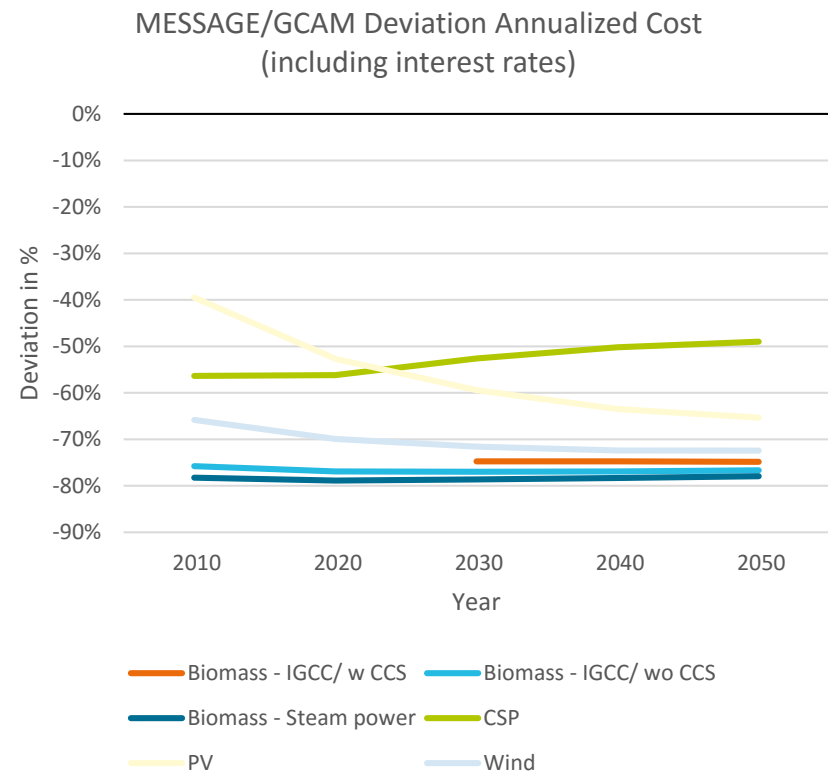
Технологии возобновляемой энергетики - капитальные затраты, эксплуатационные расходы



# Summary: Deviation between GCAM and MESSAGE

## резюме – девиация между моделями GCAM и MESSAGE

- Renewable power generation technologies – comparison of the deviation between MESSAGE and GCAM of annualized cost with the inclusion of interest rates over time
- Технологии возобновляемой энергетики - Годовая стоимость с включением процентных ставок
- deviations for all renewable power generation are similar (50-80%)
- отклонения для всех возобновляемых технологий аналогичны

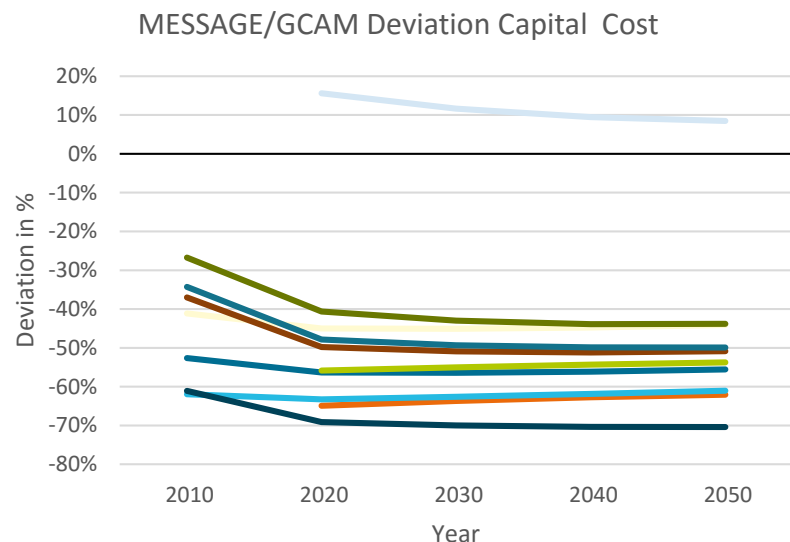


# Summary: Deviation between GCAM and MESSAGE

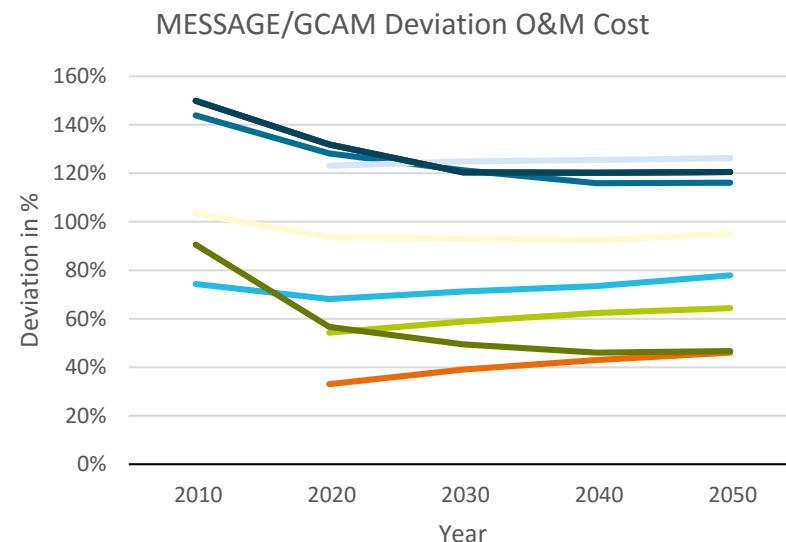
## резюме – девиация между моделями GCAM и MESSAGE

Conventional generation technologies – comparison of the deviation of capital and O&M cost over time

традиционные технологии - капитальные затраты, эксплуатационные расходы



Coal-IGCC/w CCS Coal-IGCC/wo CCS  
Coal-Subcritical Coal-Supercrit/ w CCS  
Coal-Supercrit/ wo CCS Gas - GCC/ w CCS  
Gas - GCC/ wo CCS Gas - Steam power  
Gas - Turbine power Nuclear



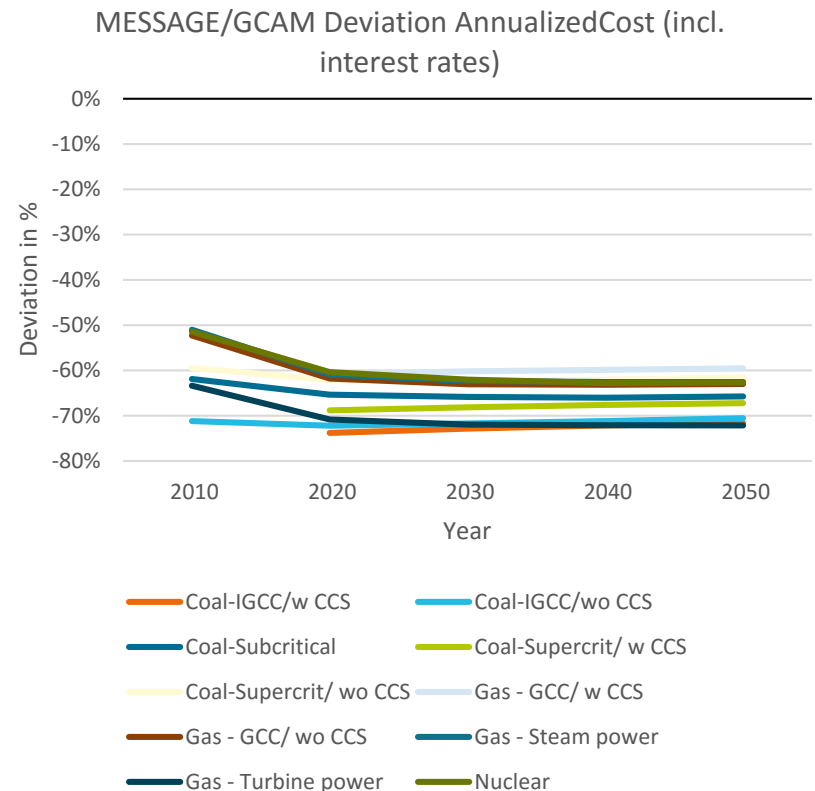
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# Summary: Deviation between GCAM and MESSAGE

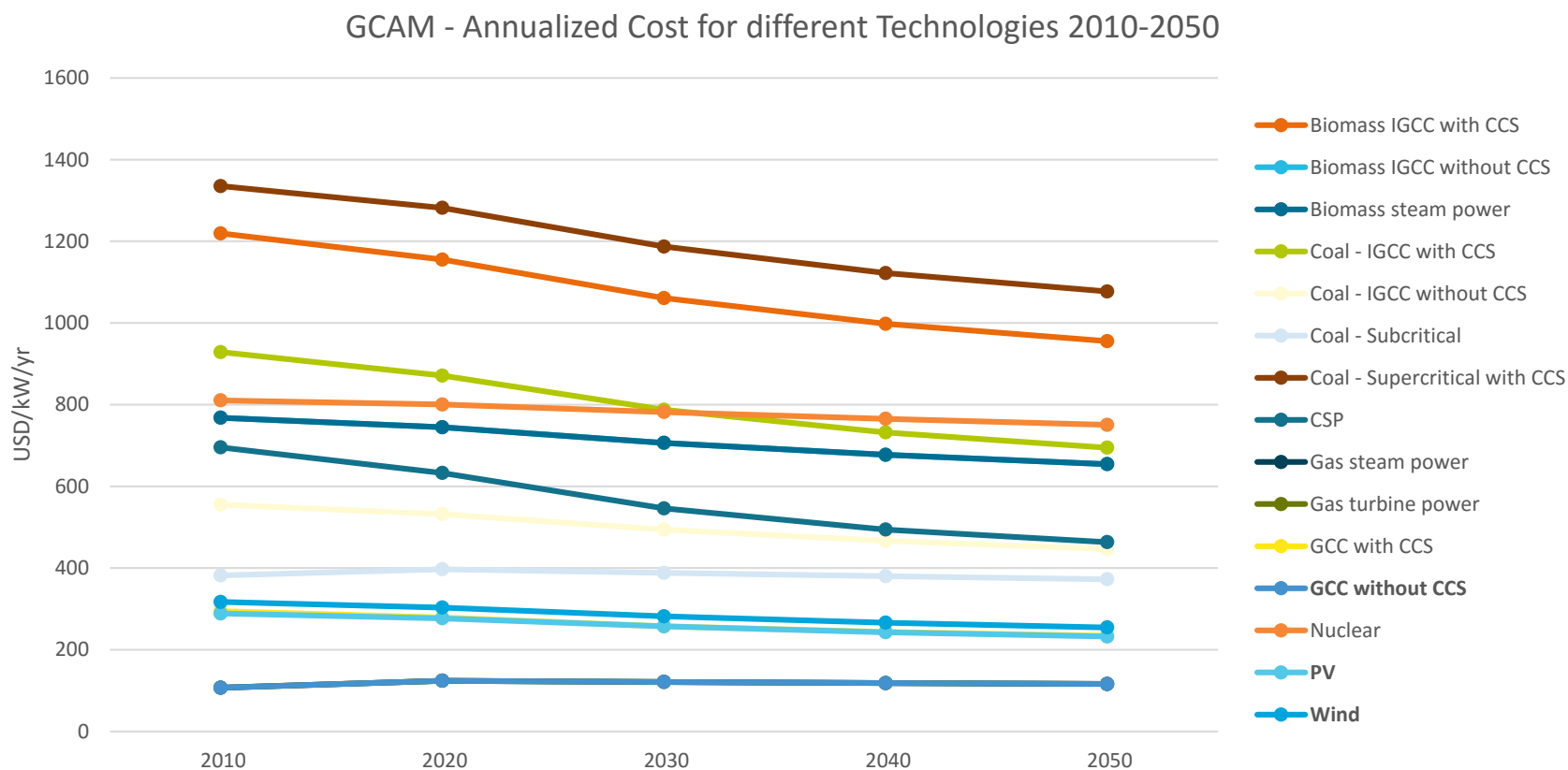
## резюме – девиация между моделями GCAM и MESSAGE

- Conventional power generation technologies – comparison of the deviation between MESSAGE and GCAM of annualized cost with the inclusion of interest rates over time
- традиционные технологии - Годовая стоимость с включением процентных ставок
- deviations for all conventional power generation are similar (50-70%)
- отклонения для всех традиционных технологий аналогичны



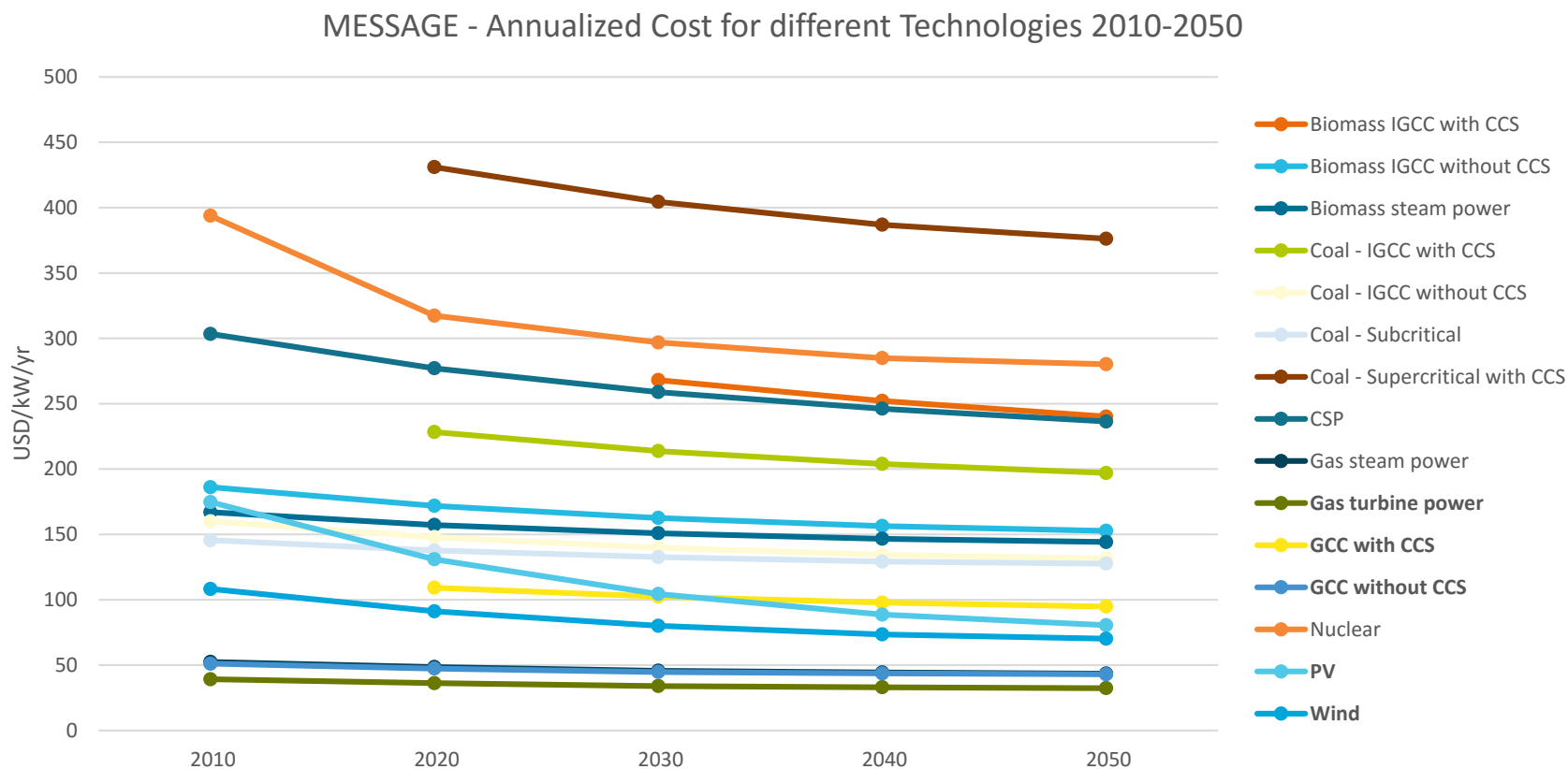
# Results: Annualized Cost of different technologies 2010-2050

## результаты - Годовая стоимость различных технологий 2010-2050 гг модели GCAM



# Results: Annualized Cost of different technologies 2010-2050

## результаты - Годовая стоимость различных технологий 2010-2050 гг модели MESSAGE



# Results: Ranking of Annualized Cost from both models

## результаты: ранжирование годовой стоимости различных технологий

GCAM	Ranking 2050		MESSAGE
Technology	<i>lowest first</i>		Technology
Gas Steam	1	1	Gas Turbine
Gas Turbine	1	2	GCC
GCC	1	3	Gas Steam
PV	4	4	Wind
GCC w/CCS	5	5	PV
Wind	6	6	GCC w/CCS
Coal Subcritical	7	7	Coal Subcritical
Coal IGCC	8	8	Coal IGCC
CSP	9	9	Biomass Steam
Biomass Steam	10	10	Biomass IGCC
Biomass IGCC	10	11	Coal IGCC w/CCS
		12	Hydro
Nuclear	12	13	CSP
Coal IGCC w/CCS	13	14	Biomass IGCC w/CCS
Biomass IGCC w/CCS	14	15	Nuclear
Coal Super Critical w/CCS	15	16	Coal Super Critical w/CCS

# Results: Ranking of Annualized Cost from both models

## Обсуждение результатов

- Lowest annualized technology costs:
- самые низкие годовые стоимости различных технологий:
  - **GCAM:** Wind, PV, GCC without CCS
  - **MESSAGE:** Gas turbine power, GCC without CCS, Wind, PV (by 2050), GCC with CCS
- Highest annualized technology costs:
- самые высокие годовые стоимости различных технологий:
  - **GCAM:** Coal supercritical with CCS, Biomass IGCC with CCS
  - **MESSAGE:** Coal supercritical with CCS, Nuclear, Biomass IGCC with CCS

# Results: Ranking of Annualized Cost from both models

## Обсуждение результатов

- For some technologies we found widely spread literature data. Uncertainty in the future development of a specific technology leads to higher variations in the projected costs.
- Для некоторых технологий мы нашли широко разбросанные литературные данные.
- MESSAGE and GCAM assumptions on the reviewed parameters differ considerably for some technologies, but the deviations for renewable and conventional power generation are similar (50-70%)
- предположения MESSAGE and GCAM по рассмотренным параметрам для некоторых технологий расходятся, но отклонения аналогичны (50-70%)

**Thank you for your attention!**

**Спасибо за внимание!**

**Q & A**

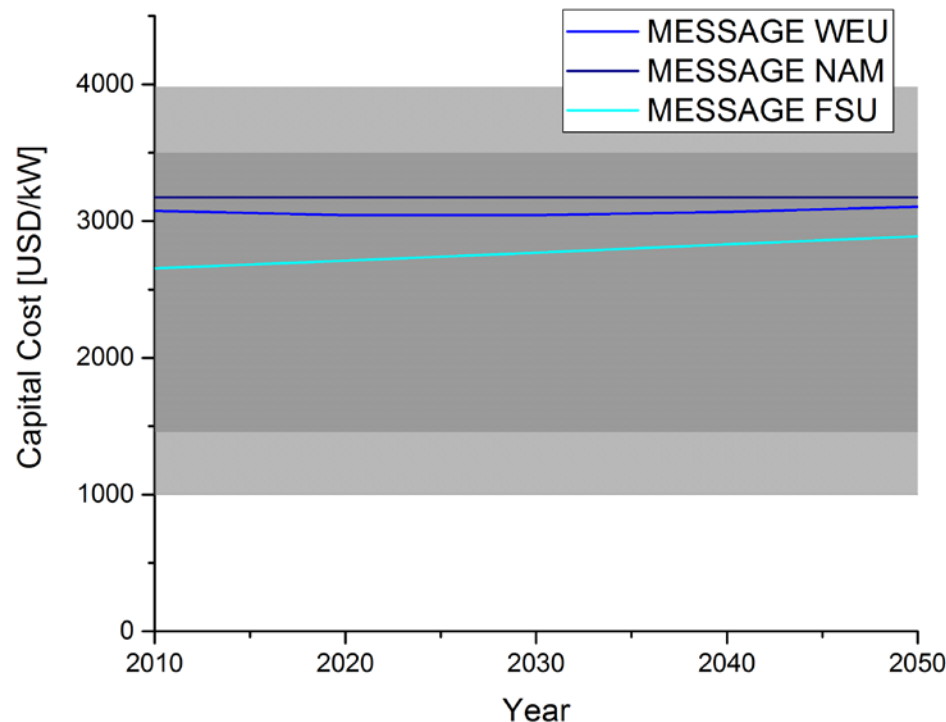
# Results – Example Renewable: Hydro

## результаты - Пример Возобновляемые источники энергии: гидроэнергетика

- **Capital Cost**

- **Капитальные затраты**

- Input Assumptions of MESSAGE fit into the upper half of literature data
- исходные предположения MESSAGE соответствуют верхней половине диапазона данных литературы
- MESSAGE assumes light increase in capital costs for the eastern UNECE region
- увеличение капитальных затрат для восточного региона ЕЭК ООН



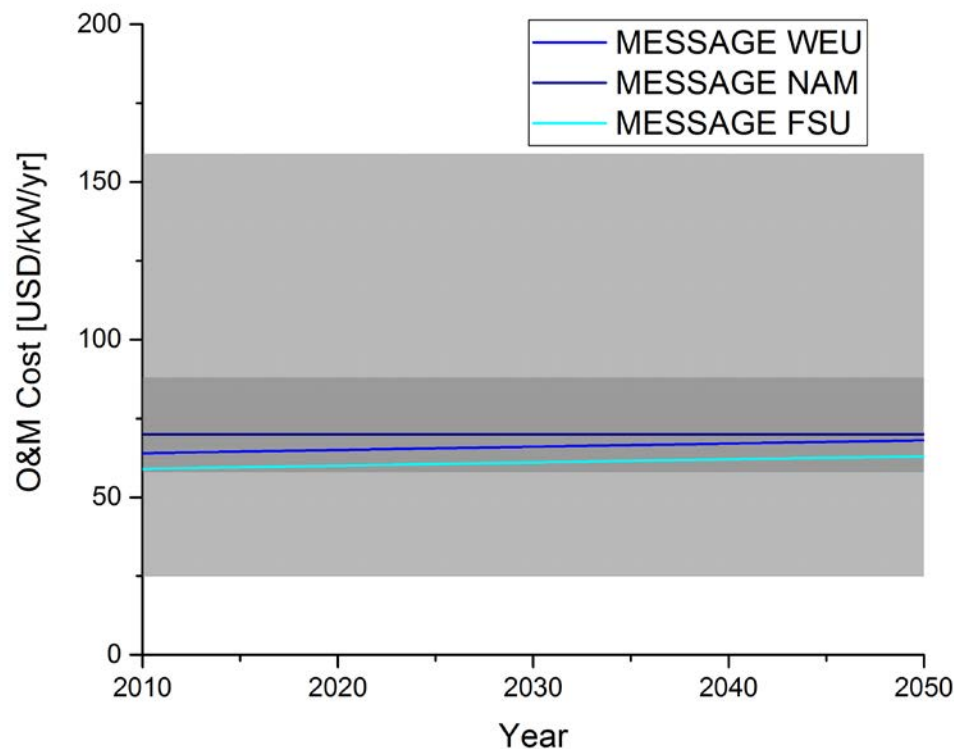
Comparison of literature values (grey area) and the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)



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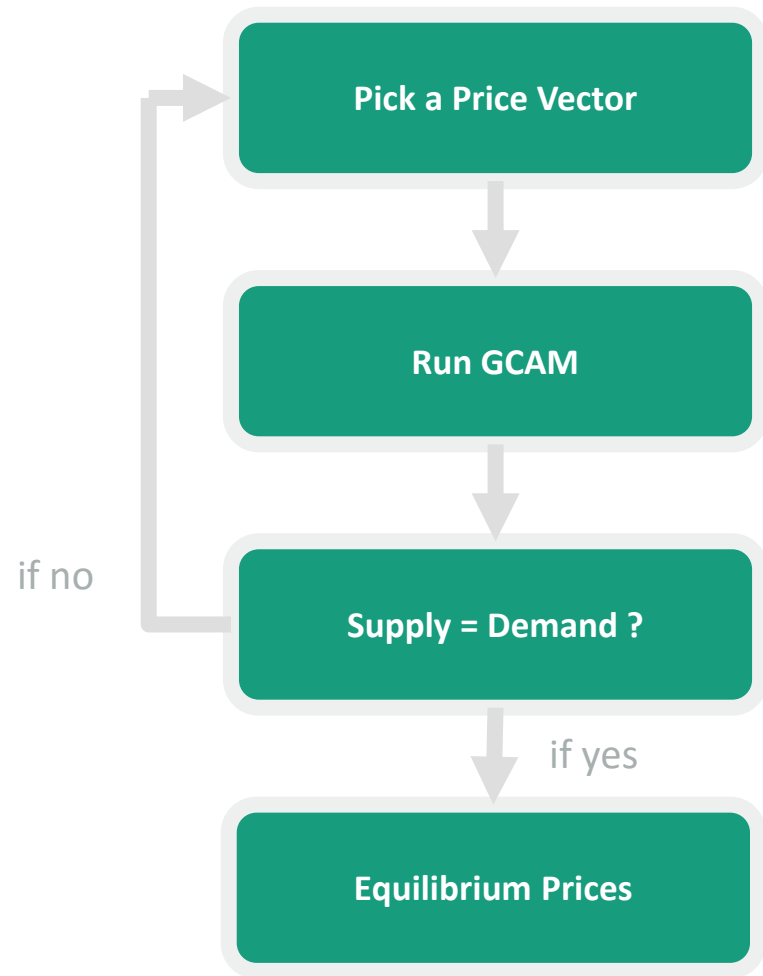
- **Operation and Maintenance Cost**
- **СТОИМОСТЬ эксплуатации и обслуживания**
  - Input Assumptions of MESSAGE fit into the upper half of literature data
  - исходные предположения MESSAGE соответствуют нижней половине диапазона данных литературы



Comparison of literature values (grey area) and the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)

# GCAM Technology Costs

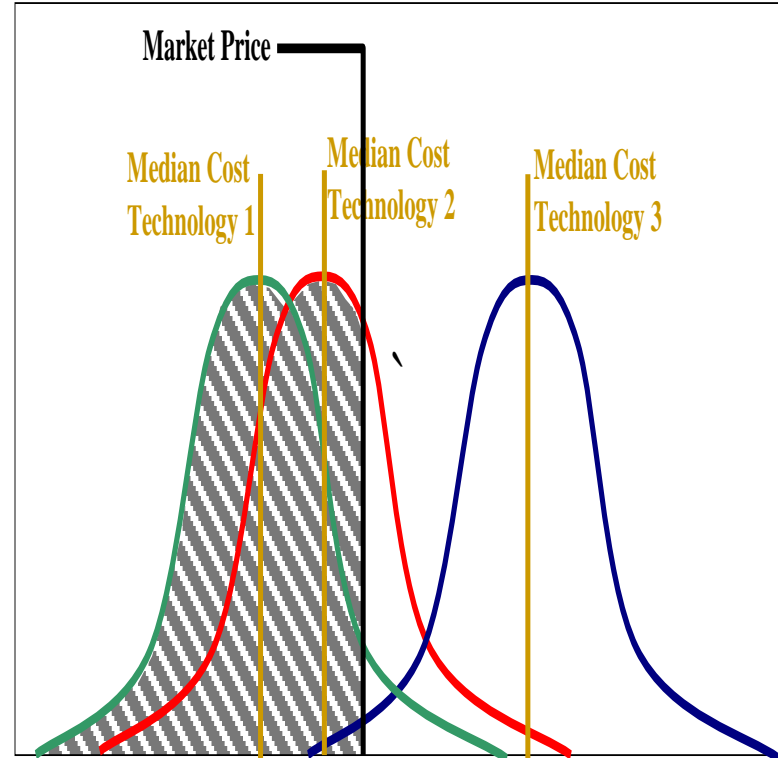
- How **prices** are computed:
  - Socioeconomic inputs (SSP2) „generate“ demand for services from different sectors
  - Supply curves for raw materials etc. define supply
  - Price vector with initial „guess“ prices
  - GCAM computes demand disequilibrium and iterates through price vector until supply and demand match
  - This is repeated for every new time period (myopic model)



# GCAM Technology Costs – Technology Competition

- Cost of technology:

- $C_i = g_i + h_j P_j + T_i$
- $C_i$  = total unit cost
- $g_i$  = **non-fuel input cost**  
(costs analyzed in portfolio)
- $h_j$  = no. Of fuel input units  $j$  to produce one output unit  $i$
- $P_j$  = price of fuel input  $j$
- $T_i$  = other costs e.g. carbon tax



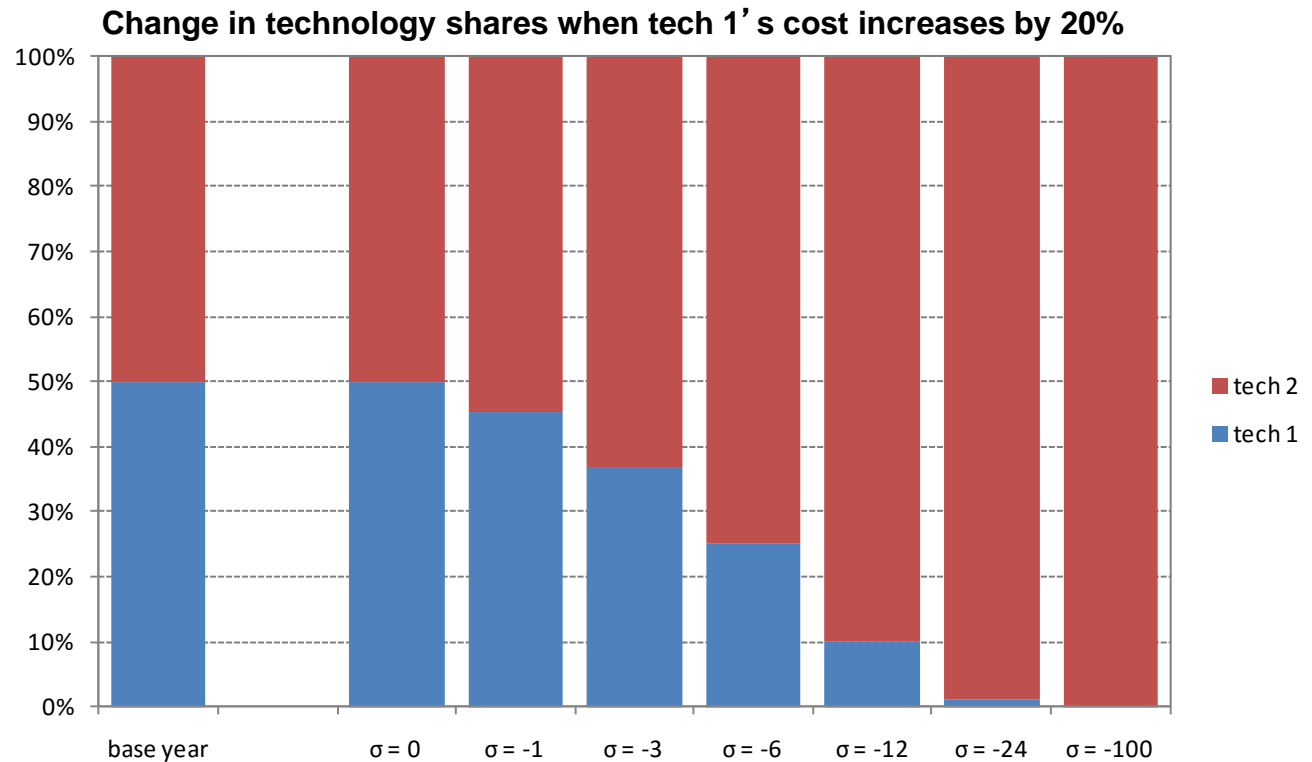
- Economic competition assumes a distribution of realized costs in an attempt to capture non-price related factors
- Market share based on probability that the technology has the least cost
- Avoids „winner take all“ scenario

# GCAM Technology Costs – Technology Competition

- Logit function for changes in cost
  - $s_i$  = market share of technology
  - $\alpha_i$  = logit parameter
  - $c_i$  = cost of technology  $i$
  - $\sigma$  = logit parameter
- Appropriate  $\sigma$  is chosen
- $\alpha$  determined through calibration with historical data (using the given  $\sigma$ )

$$s_i = \frac{\alpha_i c_i^\sigma}{\sum_j \alpha_j c_j^\sigma}$$

Source: Clarke and Edmonds (1993), McFadden (1974)



# MESSAGE Technology Costs

- MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with user-defined constraints.
- The model minimizes total costs while satisfying given demand levels for commodities/services and considering a broad range of technical/engineering constraints and societal restrictions (e.g. bounds on GHG emissions)
- The optimal solution selects the most appropriate option with respect to the calculated discounted cost of the delivered energy unit taking into account the whole technology cost of investment operation and maintenance (O&M) and fuel cost at constant price of the base year

# MESSAGE Technology Costs

The objective function of MESSAGEix core model minimizes total discounted systems costs including costs for emissions, relaxations of dynamic constraints

$$OBJ = \sum_{n,y} discount\ factor_y \cdot COST\_NODAL_{n,y}$$

Equation COST\_NODAL: Accounting of regional system costs over time

(as well as costs for emissions, technology, land use, relaxations of dynamic constraints and linear relations.)

The implementation of MESSAGE includes specified upper and lower bounds on new capacity and activity, as constraints on market penetration and rate of expansion or phase-out of technology

# Results – Model comparison summary: Deviation between GCAM and MESSAGE

Results for renewable and nuclear power generation technologies - negative values indicate that GCAM assumptions are higher than those made by MESSAGE. The reverse is true for **positive values**.

Technology	Category	Deviation between GCAM and MESSAGE		
		2010	2030	2050
PV	Capital Cost	31%	-12%	-25%
	O&M Cost	-62%	-74%	-77%
	Annualized Cost (I)	-40%	-59%	-65%
CSP	Capital Cost	-40%	-35%	-30%
	O&M Cost	83%	98%	113%
	Annualized Cost (I)	-56%	-53%	-49%
Wind	Capital Cost	-38%	-49%	-50%
	O&M Cost	-44%	-54%	-54%
	Annualized Cost (I)	-66%	-72%	-72%
Biomass - IGCC/ w CCS	Capital Cost		-66%	-66%
	O&M Cost		-24%	-26%
	Annualized Cost (I)		-75%	-75%
Biomass - IGCC/ wo CCS	Capital Cost	-67%	-68%	-68%
	O&M Cost	-43%	-46%	-45%
	Annualized Cost (I)	-76%	-77%	-77%
Biomass - Steam power	Capital Cost	-72%	-72%	-70%
	O&M Cost	-43%	-46%	-45%
	Annualized Cost (I)	-78%	-79%	-78%
Nuclear	Capital Cost	-27%	-43%	-44%
	O&M Cost	91%	49%	47%
	Annualized Cost (I)	-51%	-62%	-63%

Annualized cost (I): including interest rates

# Results – Model comparison summary: Deviation between GCAM and MESSAGE

Results for conventional power generation technologies - negative values indicate that GCAM assumptions are higher than those made by MESSAGE. The reverse is true for positive values.

Technology	Category	Deviation between GCAM and MESSAGE		
		2010	2030	2050
Coal-IGCC/w CCS	Capital Cost		-64%	-62%
	O&M Cost		39%	46%
	Annualized Cost (I)		-73%	-72%
Coal-IGCC/wo CCS	Capital Cost	-62%	-63%	-61%
	O&M Cost	74%	71%	78%
	Annualized Cost (I)	-71%	-72%	-71%
Coal-Supercrit/ w CCS	Capital Cost		-55%	-54%
	O&M Cost		59%	64%
	Annualized Cost (I)		-68%	-67%
Coal-Supercrit/ wo CCS	Capital Cost	-41%	-45%	-44%
	O&M Cost	103%	93%	95%
	Annualized Cost (I)	-59%	-62%	-62%
Coal-Subcritical	Capital Cost	-53%	-56%	-56%
	O&M Cost	144%	121%	116%
	Annualized Cost (I)	-62%	-66%	-66%
Gas - GCC/ w CCS	Capital Cost		12%	8%
	O&M Cost		125%	126%
	Annualized Cost (I)		-60%	-60%
Gas - GCC/ wo CCS	Capital Cost	-37%	-51%	-51%
	O&M Cost	150%	120%	121%
	Annualized Cost (I)	-52%	-63%	-63%
Gas - Steam power	Capital Cost	-34%	-49%	-50%
	O&M Cost	150%	120%	121%
	Annualized Cost (I)	-51%	-62%	-63%
Gas - Turbine power	Capital Cost	-61%	-70%	-70%
	O&M Cost	150%	120%	121%
	Annualized Cost (I)	-63%	-72%	-72%

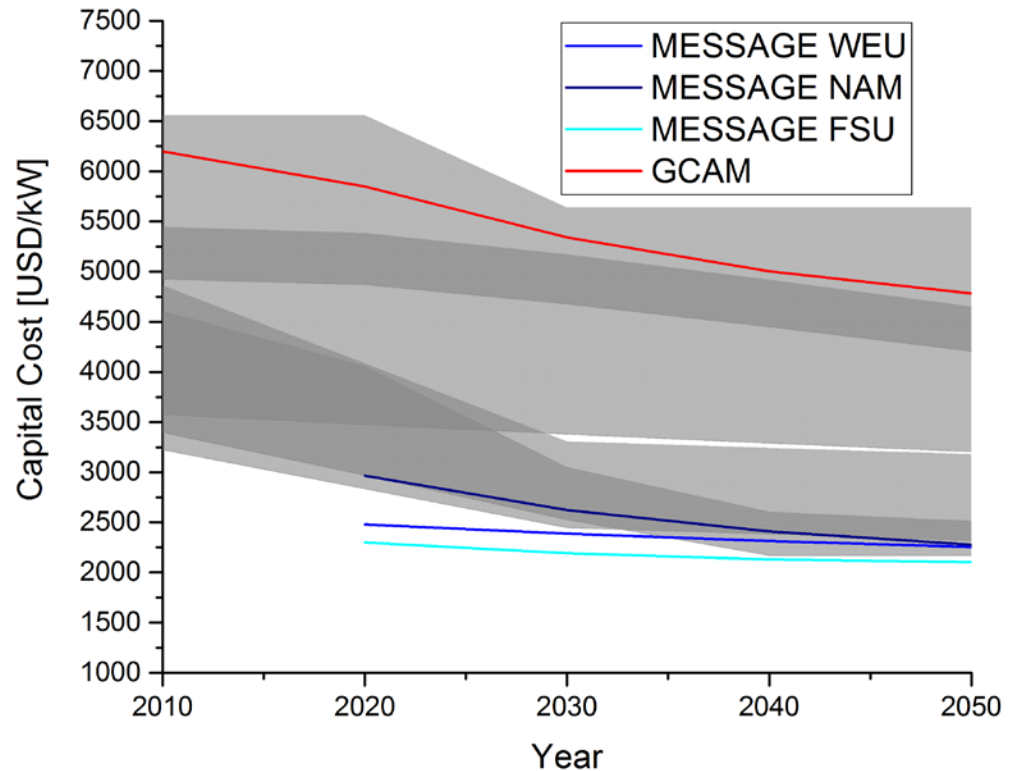
Annualized cost (I): including interest rates



# Results – Example Conventional: Supercritical coal power plant with CCS

- **Capital Cost**

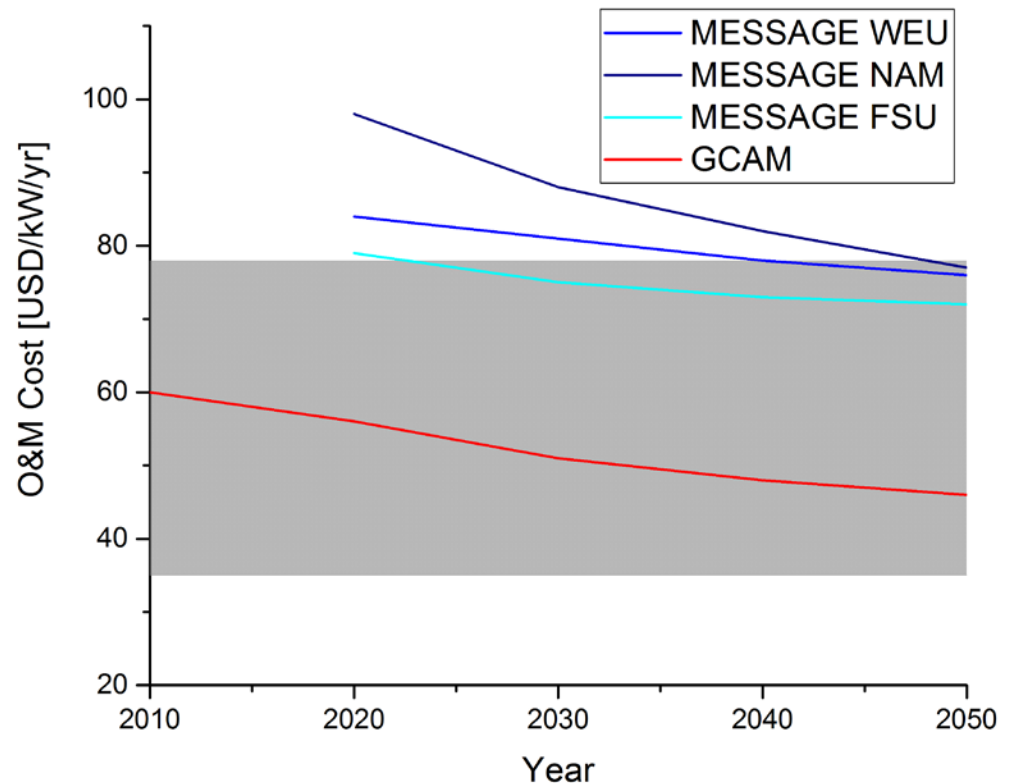
- Widely spread literature values
- Both models fit into the literature range
- Assumptions by MESSAGE and GCAM differ considerably
- GCAM's capital cost assumptions are twice as high compared to MESSAGE



Comparison of literature values (grey area) and the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)

# Results – Example Conventional: Supercritical coal power plant with CCS

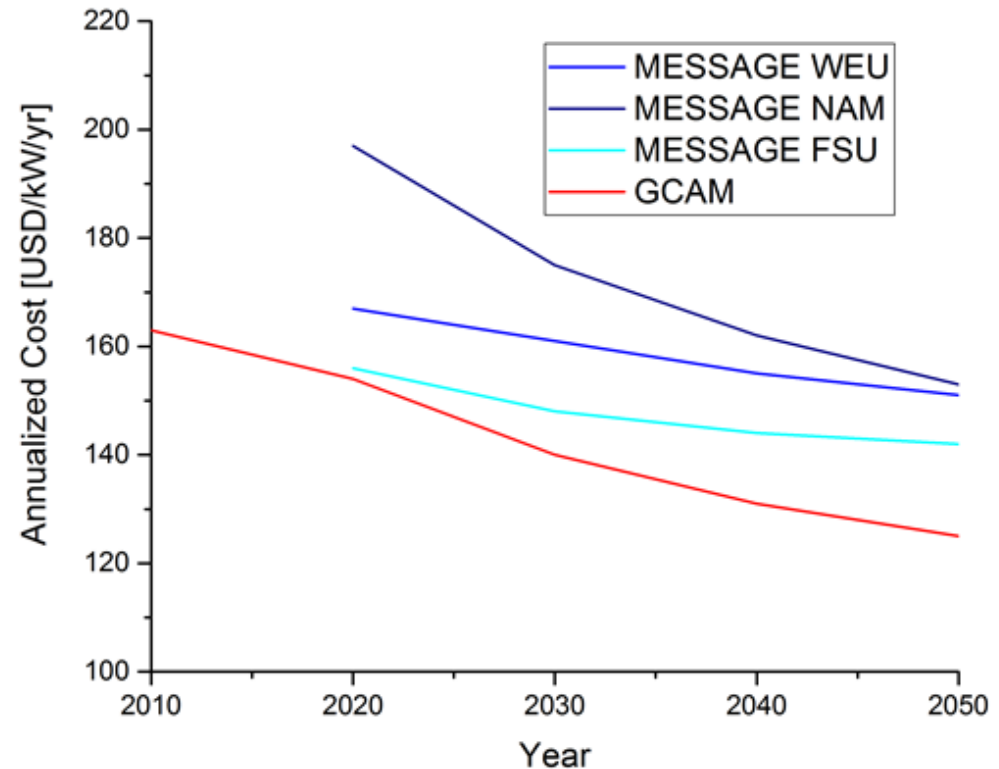
- **Operation and Maintenance Cost**
  - Reverse effect – O&M cost assumptions made by MESSAGE are higher



Comparison of literature values (grey area) and the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)

# Results – Example Conventional: Supercritical coal power plant with CCS

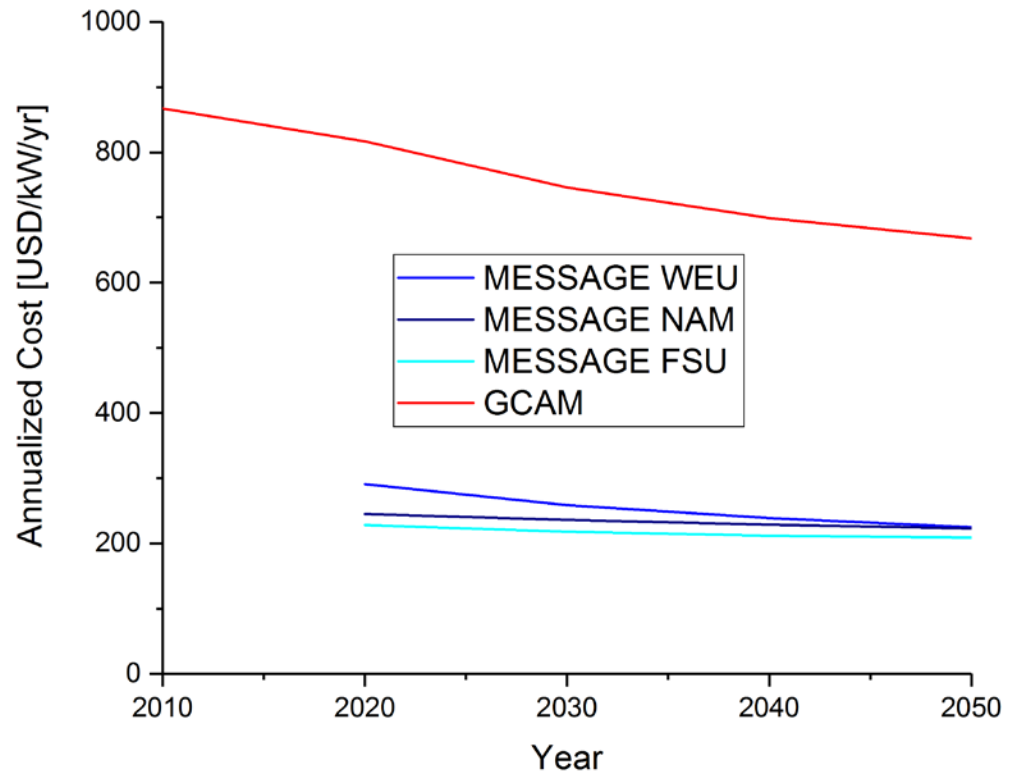
- **Annualized Cost without interest rates**
  - GCAM asset lifetime: 60 years
  - MESSAGE asset lifetime: 30 years
  - Not including interest rates brings GCAM and MESSAGE closer together



Comparison the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)

# Results – Example Conventional: Supercritical coal power plant with CCS

- **Annualized Cost with interest rates**
  - Interest Rates:
    - MESSAGE **5%**
    - GCAM **13%**
- Large difference in interest rates pulls GCAM and MESSAGE further apart



Comparison the regional assumptions from MESSAGE (WEU – Western Europe, NAM – North America, FSU – Former Soviet Union) (blue lines) and GCAM (red line)