FONDAZIONE ENI ENRICO MATTEI

A Numerical Analysis of Optimal Extraction and Trade of Oil Under Climate Policy

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1- Motivations and New Developments of the Model

Without a description of regional trade and investment of oil sector, regional stabilization cost might be biased

We introduce endogenous investments for oil extraction capacity

We can track how financial flows associated with the international trade of oil change when climate policy is introduced

Eight grades of oil are considered

Both importing and exporting regions are price takers

With these new features, in a climate policy regime oil-exporting countries bear costs twice as large if compared to previous estimates, while oil-importing regions have lower costs

The Equations

2- The Model: Supply and Demand

Oil demand:

$$OIL(t,n) = \sum_{g} (OILPROD(n,t,g)) + NIPOIL(t,n) \quad (1)$$

$$OIL(t,n) = OIL_{EL}(t,n) + OIL_{NEL}(t,n) \quad (2)$$

Oil supply:

$$OILPROD(t,n,g) \leq OILCAP(t,n,g) \quad (3)$$

$$OILCAP(t+1,n,g) = OILCAP(t,n,g)(1-\delta) + ADDOILCAP(t,n,g) \quad (4)$$

$$ADDOILCAP(t,n,g) = \frac{I_{OILCAP}(t,n,g)}{OILCAP\_COST(t,n,g)} \quad (5)$$

2- The Model: The Oil Market, Oil and Non-Oil GDP

Equilibrium in international market of oil:

$$\sum_n NIPOIL(t,n) = 0 \quad \forall\, t \tag{6}$$

Oil and Non-Oil GDP:

$$Y(t,n) = Y_{NONOIL}(t,n) + Y_{OIL}(t,n) \tag{7}$$

$$Y_{NONOIL}(t,n) = \frac{Y_{NONOIL}(t,n)}{\Omega(t,n)} - OIL(t,n)\left[P_{OIL}(t) + MKUP_{OIL}(t,n)\right] - \sum_z X_z(t,n) \tag{8}$$

$$Y_{OIL}(t,n) = \sum_g \left(OILPROD(n,t,g)\right) P_{OIL}(t) \tag{9}$$

$$C(t,n) = Y(t,n) - \sum_j I_j(t,n) - \sum_g I_{OILCAP}(t,n,g) - \sum_g OILCAP(t,n,g)\, O\&M\_COSTS - \sum_k W_k(t,n) \tag{10}$$

2- The Model: The Oil Cost Function

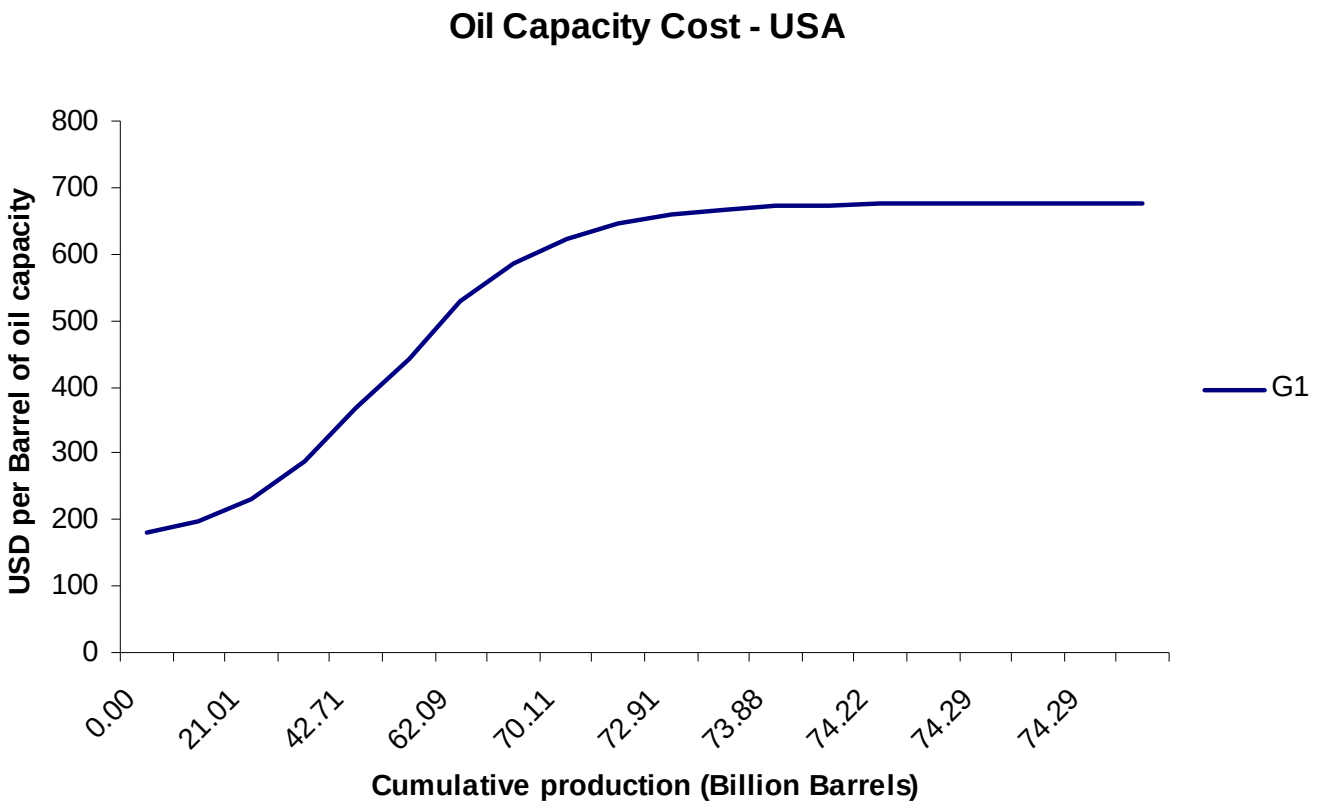
Short term component

$$OIL\_CAPCOST(t,n,g) = \alpha(g)\left\{\left[\left(\frac{ADDOIL\_CAP(t,n,g)}{ESP\_CAP(n,g)}\right)^{\psi} - 1\right] + ADDOIL\_CAP(t,n,g)^{(1/\psi)}\right\} + [\alpha(g+1) - \alpha(g)]\left(\frac{CUMOILPROD(t,n,g)}{\lambda\, OIL\_RES(t,n,g)}\right)^{\psi} \quad (11)$$

Short term component

- We model the cost of oil extraction capacity, for eight grades of oil
- Two components:
  - Short term component: avoids over-extraction in the short term
  - Long term component: costs increase as the resource is exhausted

2- The Model: The Oil Cost Function



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2- The Model: The Oil Extraction sector

The oil extraction sector:

$$CUMOILPROD(t,n,g) = \sum_{s=1}^{t-1} OILPROD(t,n,g) \quad (12)$$

$$OILRES(t+1,n,g) = OILRES(t,n,g)(1+\mu_g(t)) \quad \text{now } \mu_g(t) = 0 \quad (13)$$

$$CUMOILPROD(t,n,g) \leq OILRES(t,n,g) \quad (14)$$

Data

3- Data: Cost of Extraction Capacity

Production Cost ranges

Us $ 2005 per barrel of oil equivalent	Min	Max
G1	-	18
G2	18	29
G3	29	38
G4	38	53
G5	53	57
G6	57	78
G7	78	93
G8	93	240

Source: Rogner 1997

$$\alpha(n,g) = \text{cost of extraction capacity}$$

$$\text{cost per barrel} = \frac{\alpha(n,g)(r+\delta)}{1}$$

$$\alpha(n,g) = \frac{\text{cost per barrel}}{(r+\delta)}$$

Oil Cost: $ per barrel of installed capacity

Us $ 2005	Cost of extraction capacity (α)
G1	120
G2	190
G3	250
G4	350
G5	380
G6	520
G7	620
G8	1600

G1= Proved Recoverable Reserves
G2= Estimated Additional Reserves
G3= Additional Speculative Resources
G4= Enhanced Recovery
G5= Unconventional Recoverable Reserves
G6= Unconventional Resources
G7= Unconventional Additional Occurrences
G8= Unconventional Additional Occurrences

3- Data: Oil Resources

Billion Barrels

Source: Adapted from Rogner, 1997

Regions \ Oil grades	USA	WEURO	EEURO	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LACA
G1	74	41	2	3	13	125	644	29	7	37	21	128
G2	75	15	1	2	13	100	125	25	2	34	12	65
G3	59	26	4	4	10	141	161	36	4	60	18	114
G4	139	37	5	5	24	172	412	40	6	54	25	139
G5	19	10	0	27	173	24	163	10	1	17	4	19
G6	800	56	4	189	570	142	290	37	2	309	35	671
G7	639	97	7	331	570	249	508	65	4	541	61	1174
G8	639	254	28	442	570	921	2045	218	26	870	169	1985

G1= Proved Recoverable Reserves
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G5= Unconventional Recoverable Reserves
G6= Unconventional Resources
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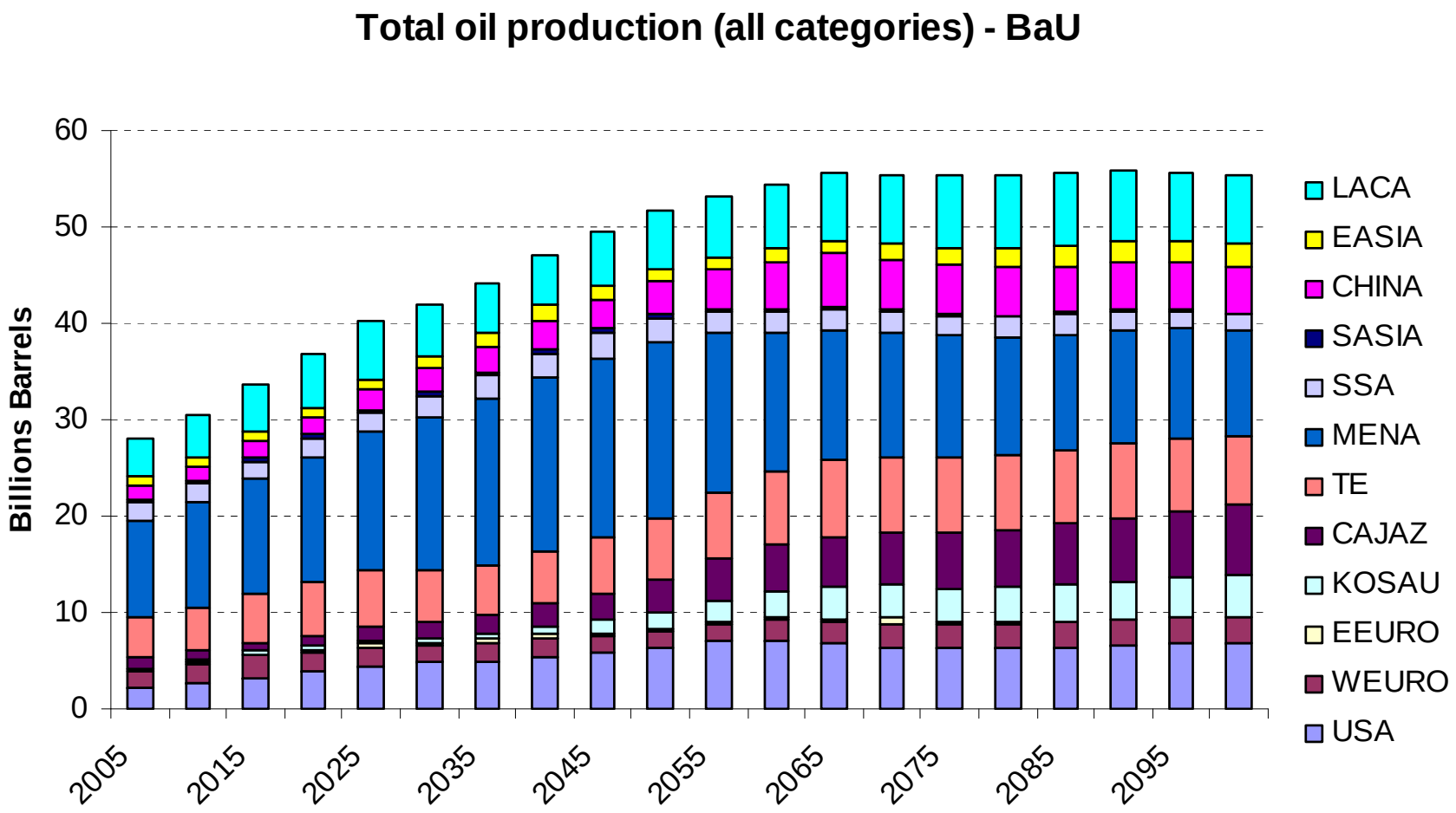
G8= Unconventional Additional Occurrences

Results: BaU

4- Results: BaU



CAJAZ and USA will increase oil production troughout the century

Oil Production in LACA remains rather constant

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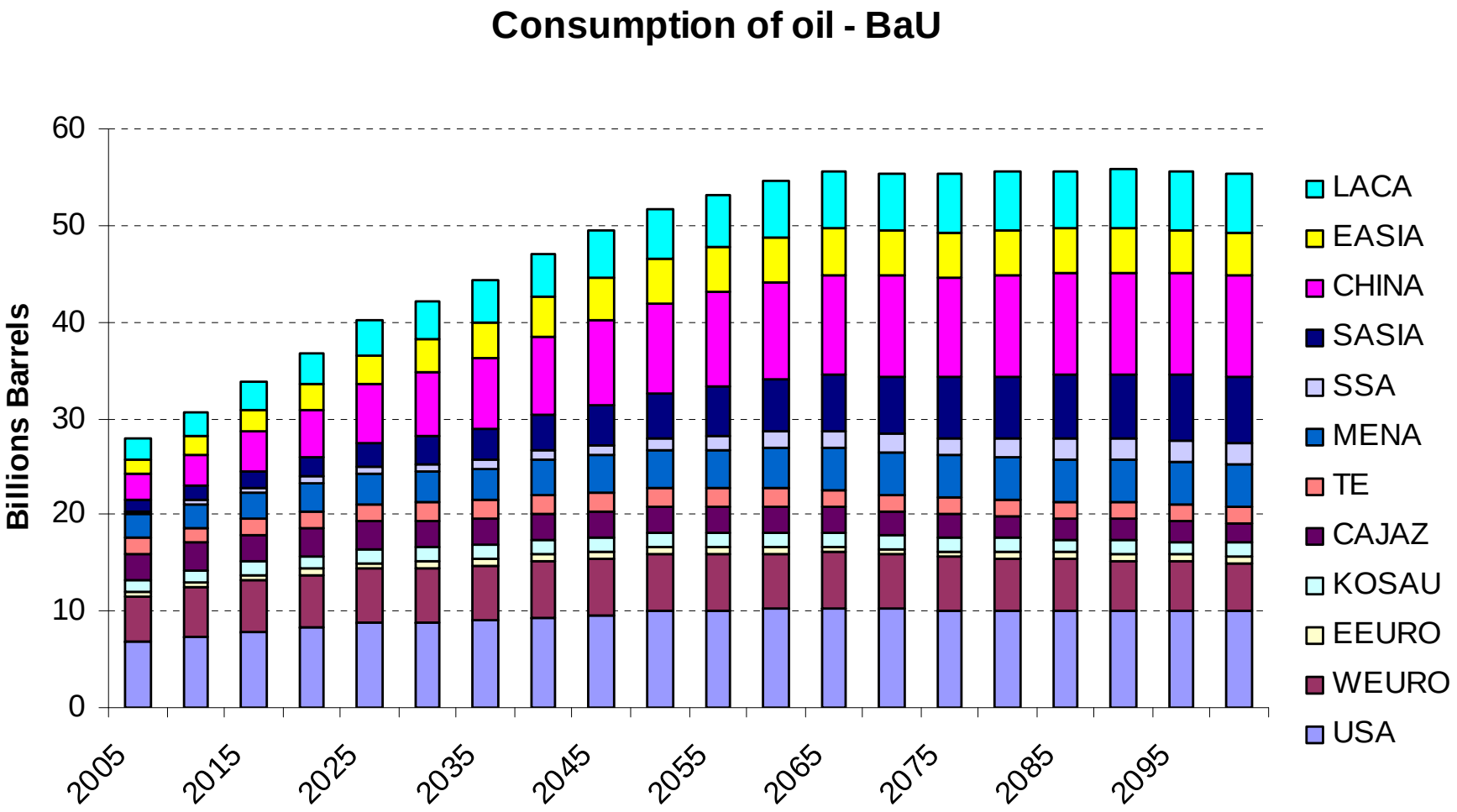
4- Results: BaU



CHINA and SASIA are going to increase oil consumption

Oil consumption in USA and Europe remained constant

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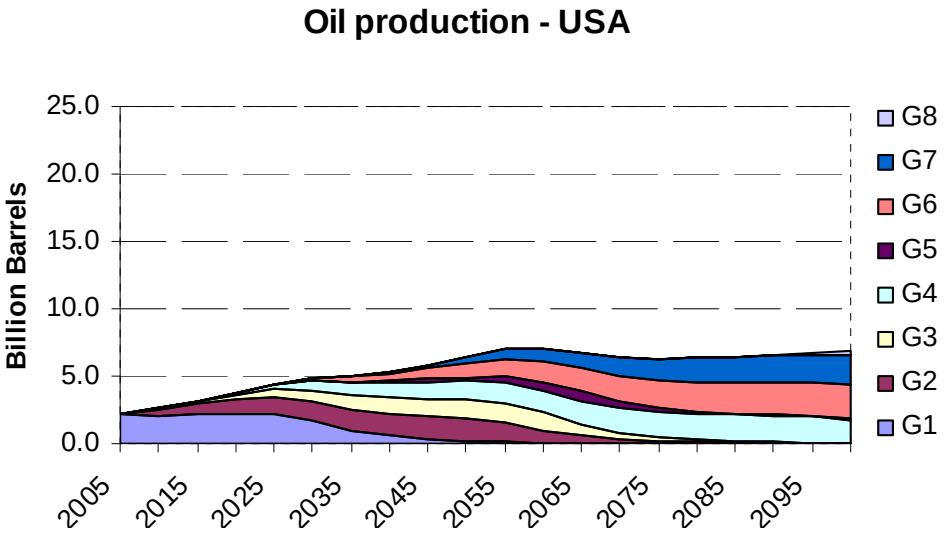
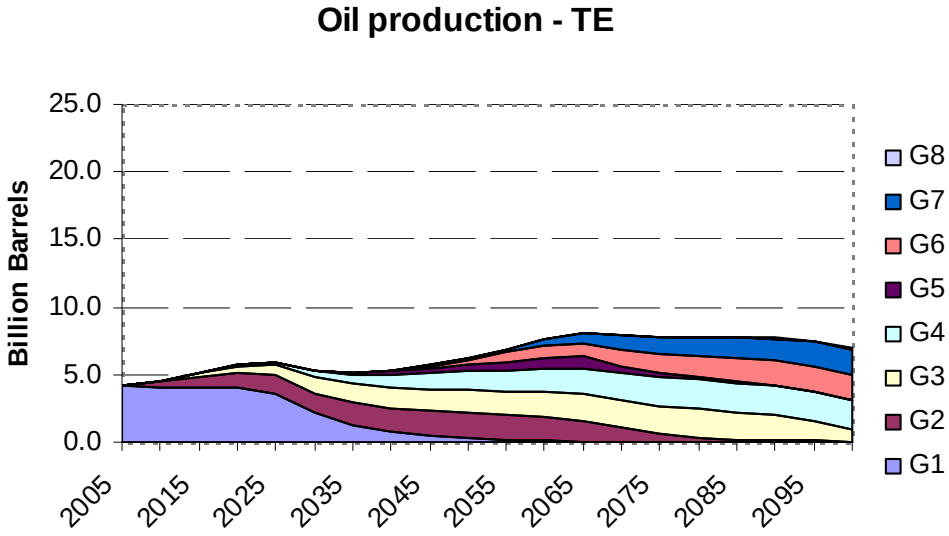
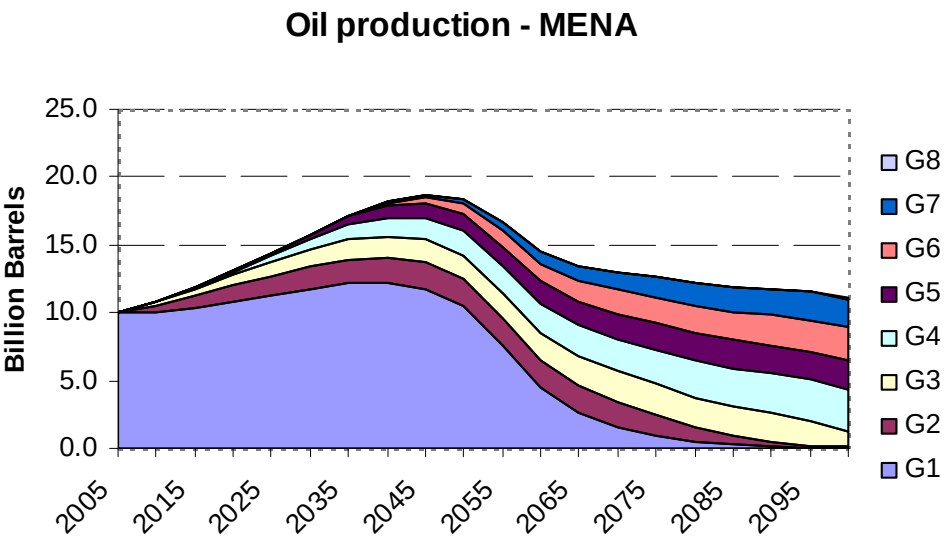
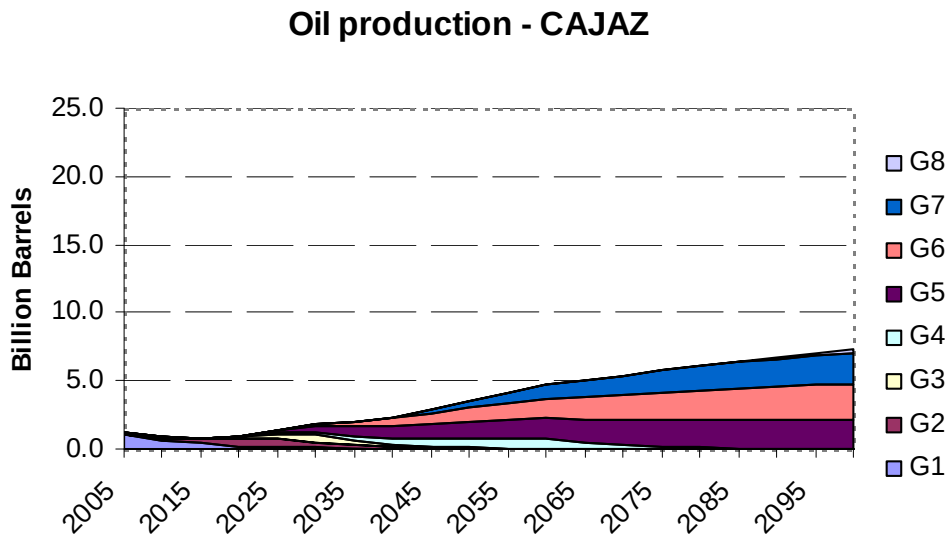
4- Results: BaU



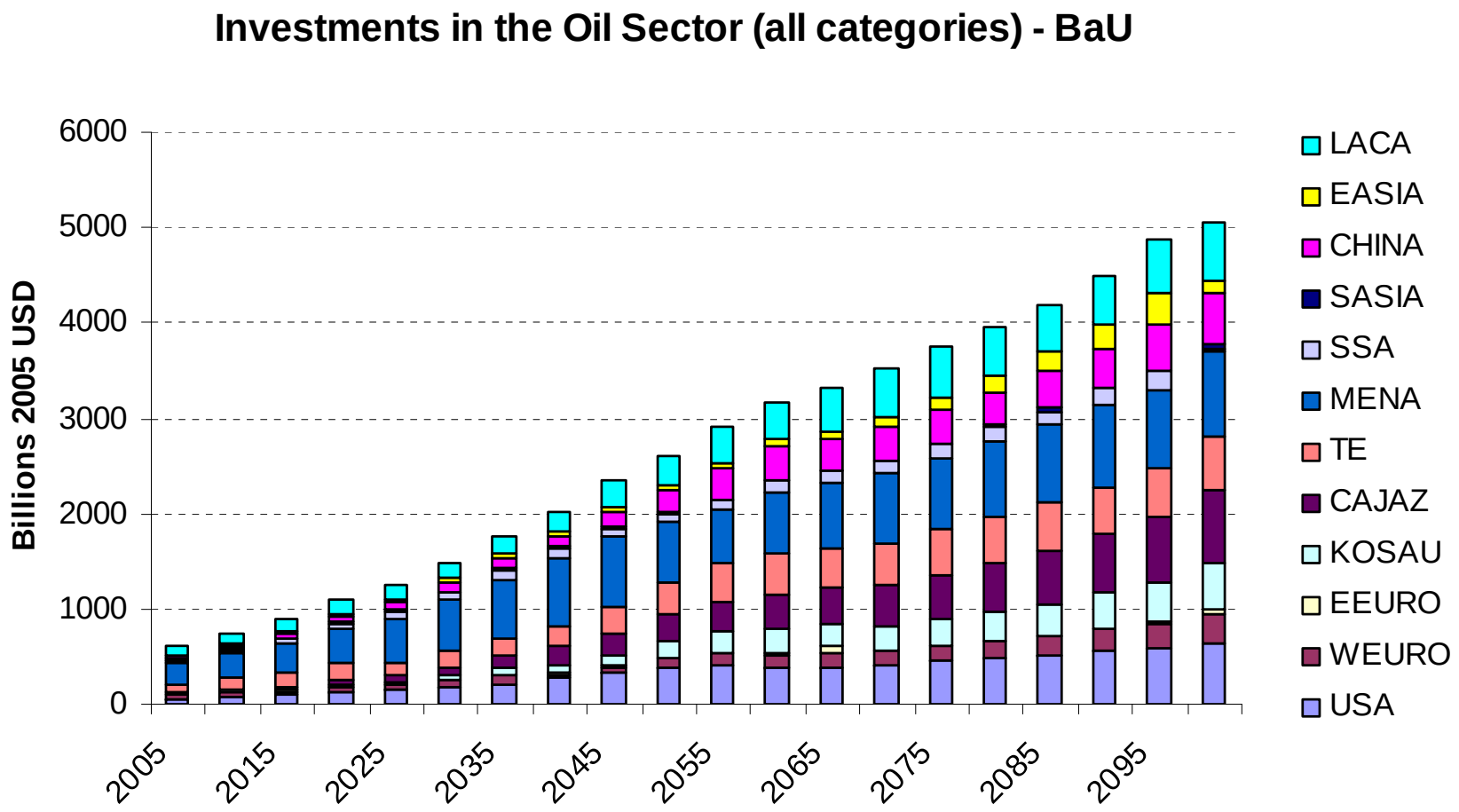






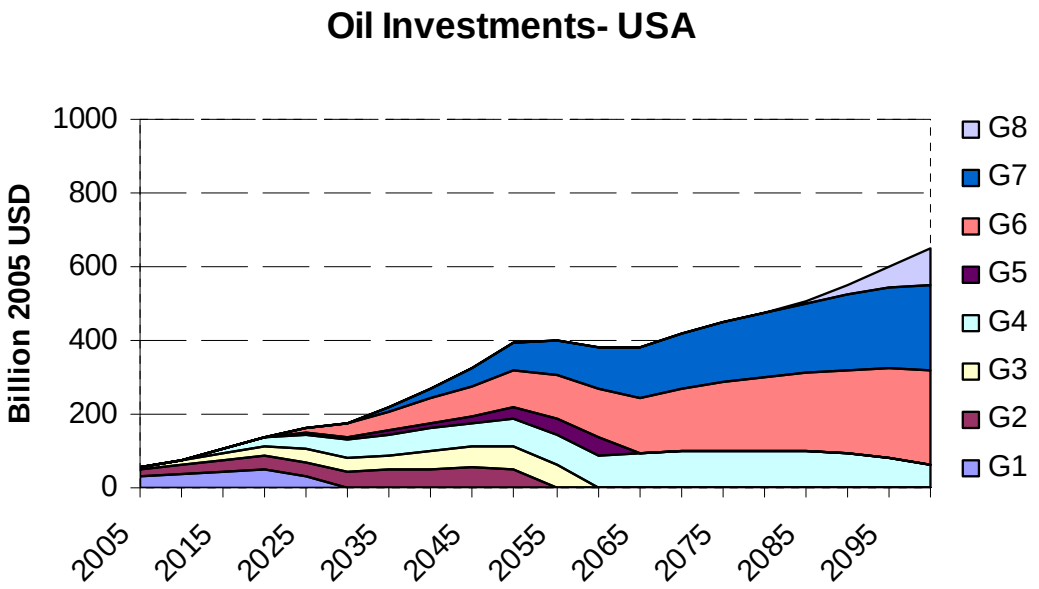
Oil production in MENA is mainly from Conventional oil (G1)

4- Results: BaU



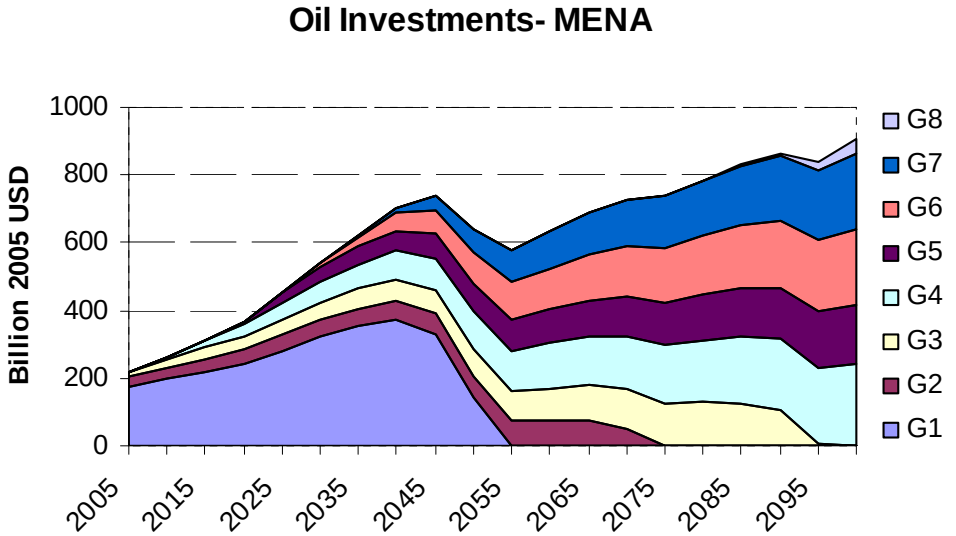
Investments are concentrated in MENA at the beginning of the century.

4- Results: BaU

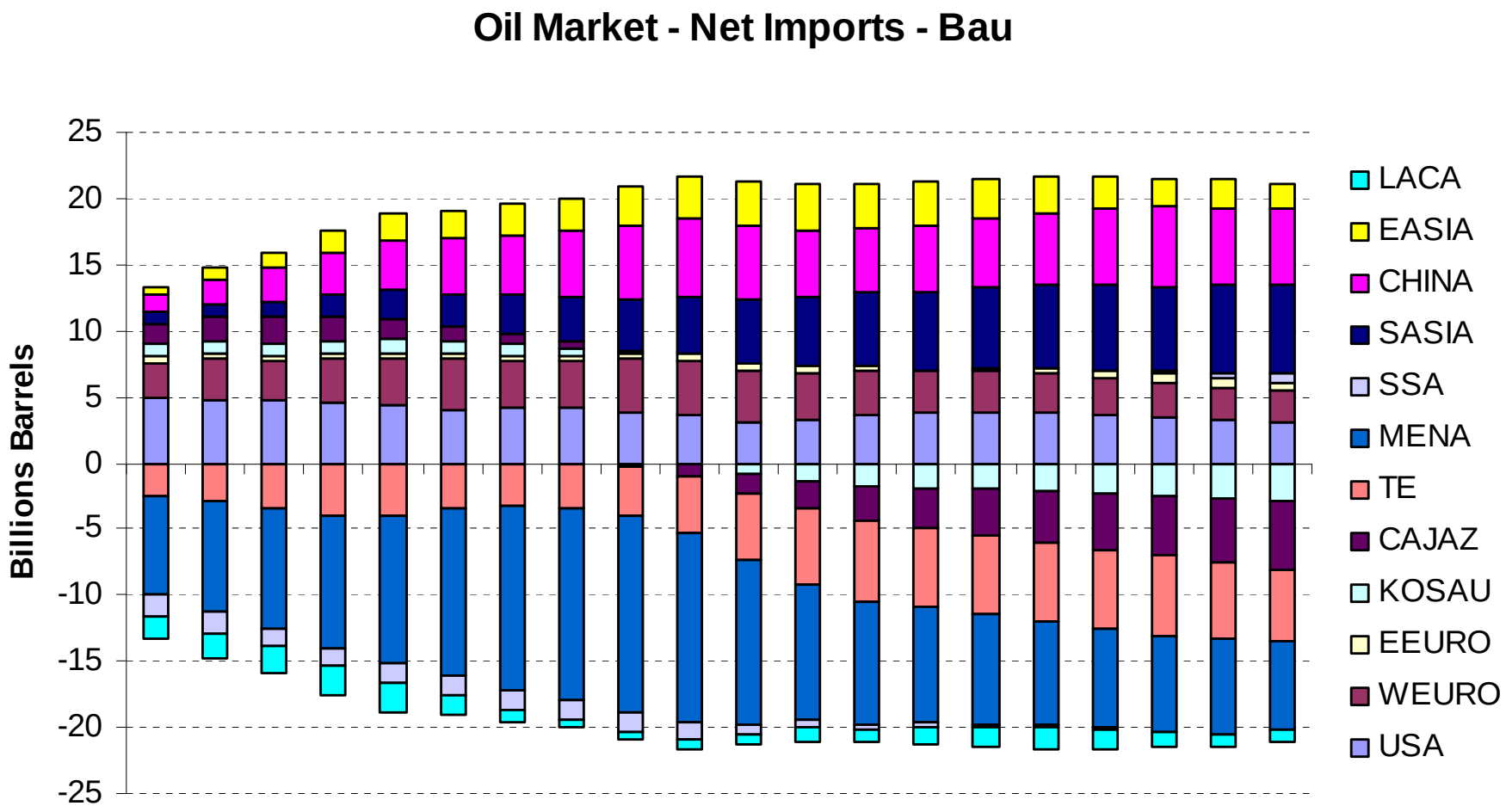


Investments in non conventional oil are dominant in the USA

Investments in MENA are related mainly to conventional oil (G1)



4- Results: BaU



Oil imports in the USA remained rather constant

CAJAZ will became an oil exporter region in 2050

Results: Stabilization Scenario

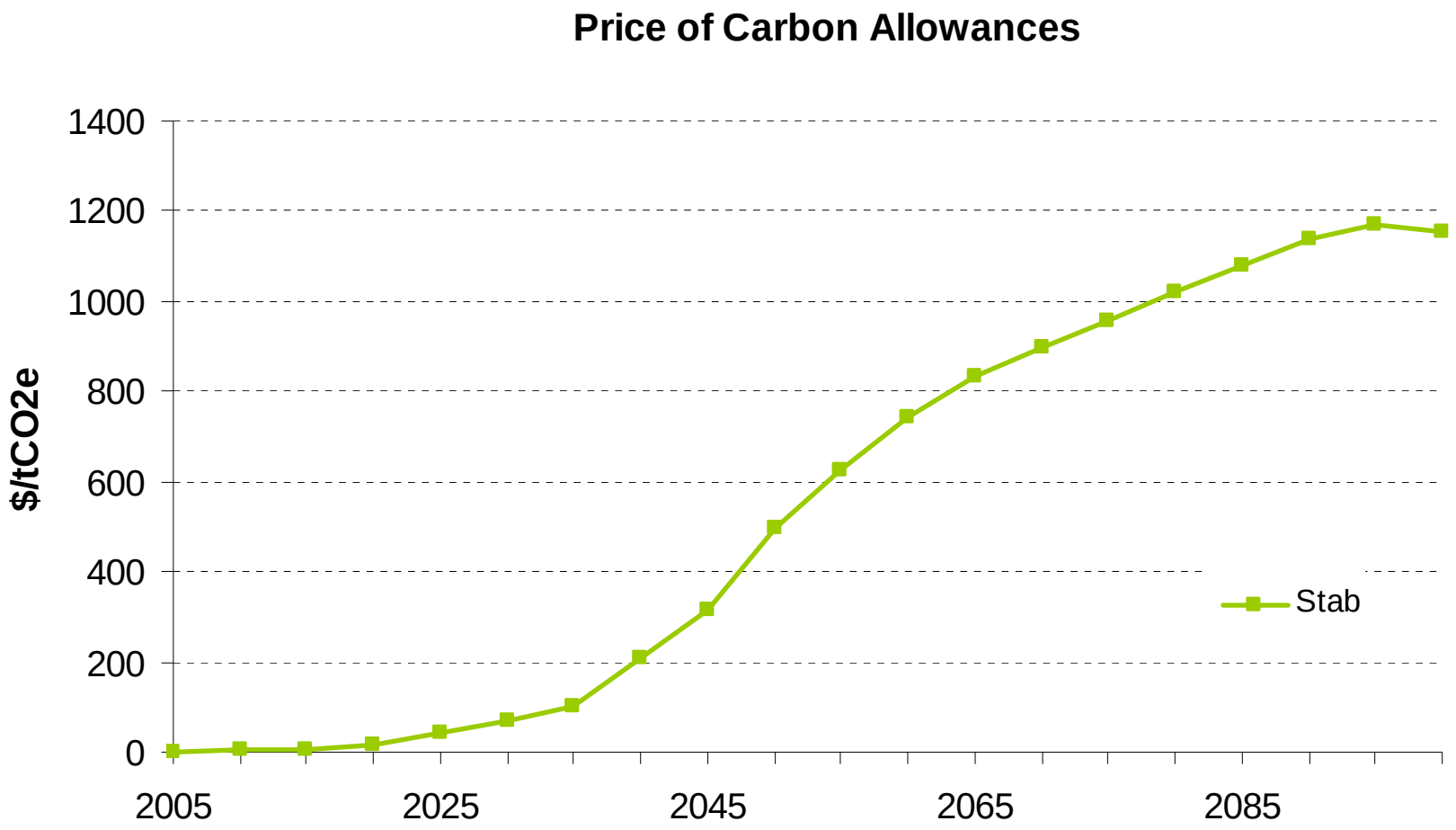
4 - Results: Stabilization Contraction and Convergence

International market for carbon permits starting at 2010

Additional CO_2 emissions of non-conventional oil (grades 5 - 8) wrt to conventional are attributed to the extraction process and thus to countries that produce non-conventional oil

It is possible to have spare capacity, but it is never an optimal choice

4 - Results: Stab



Carbon price is going to increase in a climate policy regime

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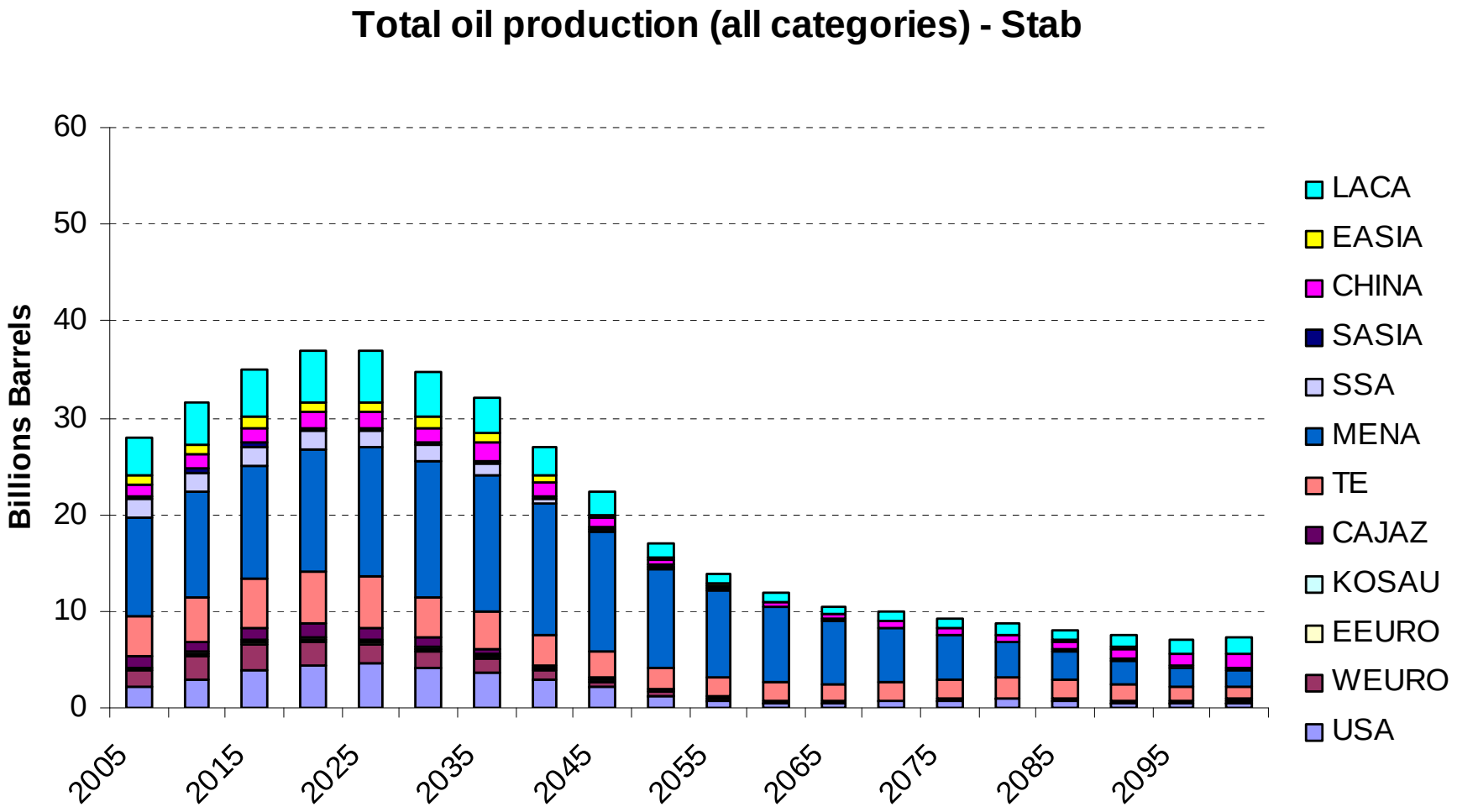
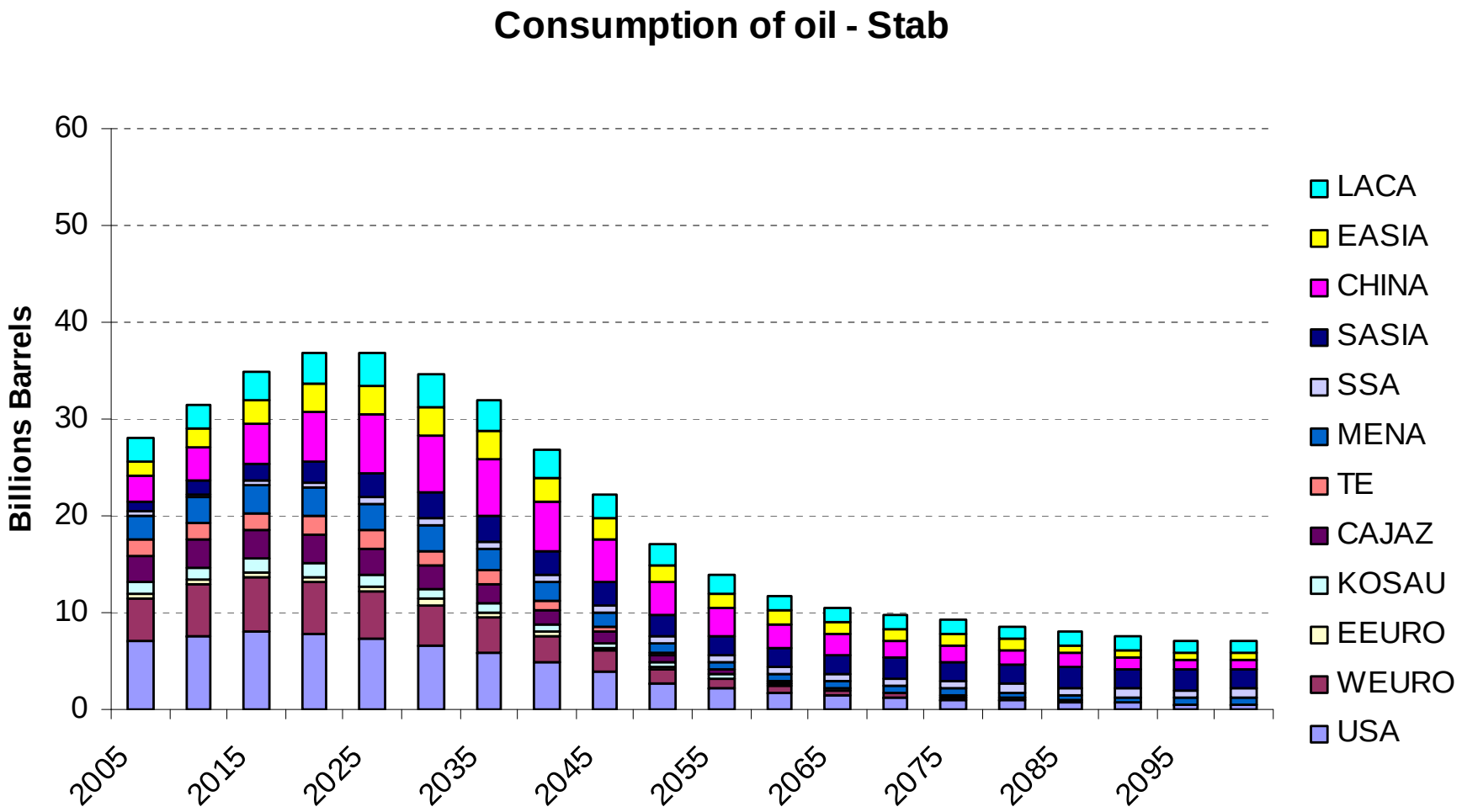
4 - Results: Stab



Oil production decrease over time.

MENA, CHINA, TE, LACA are the main producers at the end of the century

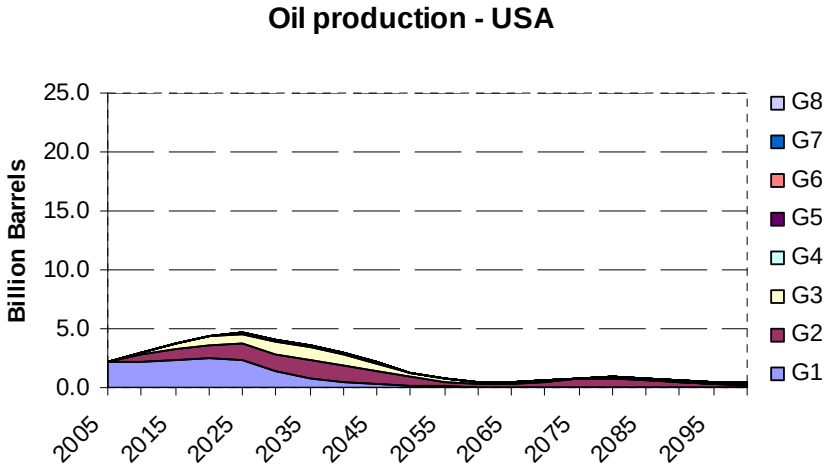
4 - Results: Stab

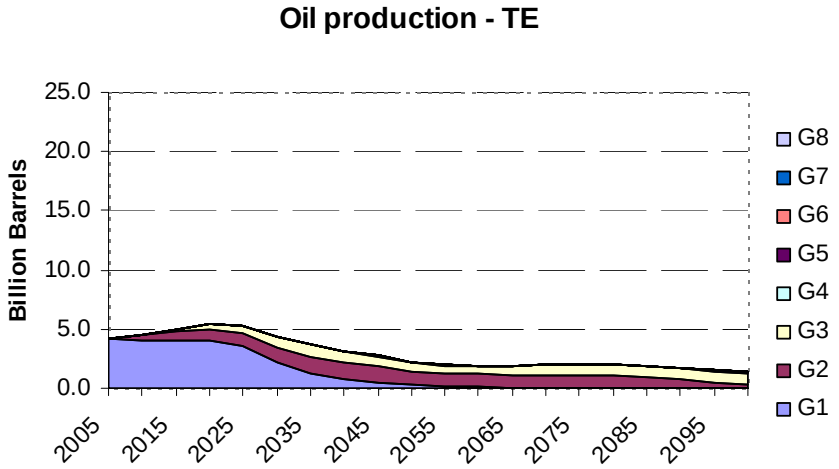


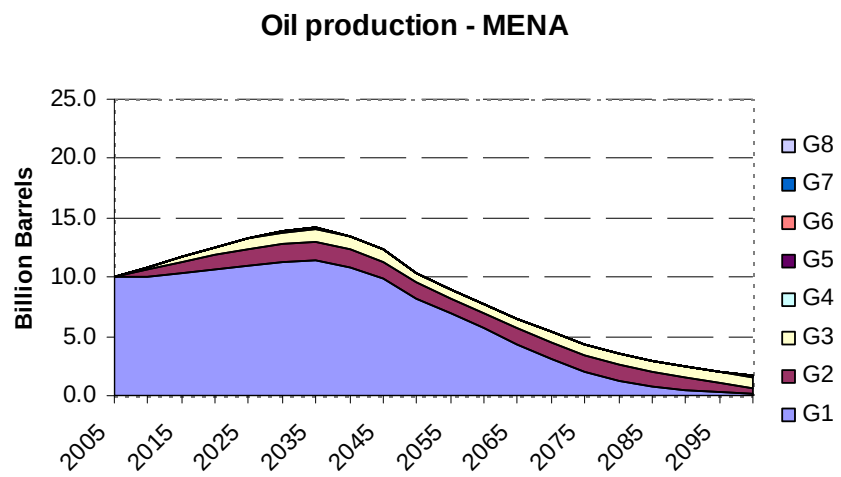
Oil is mainly consumed in SASIA, LACA and CHINA at the end of the century

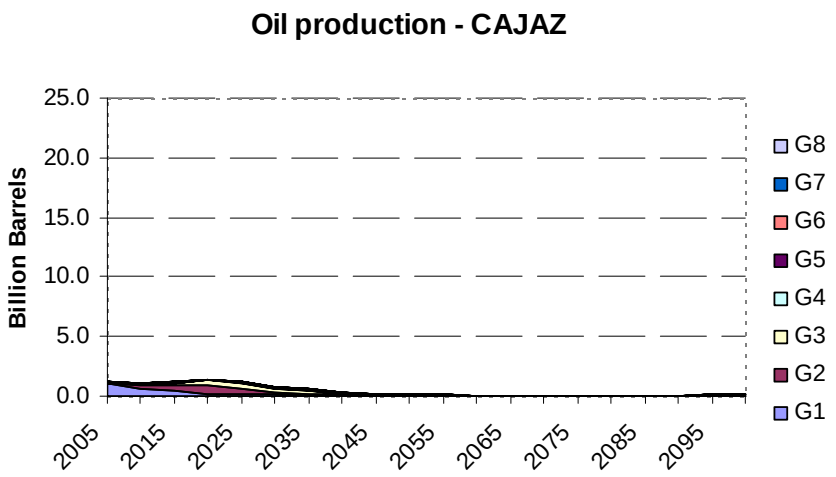
4- Results: Stab

Oil production by grade – selected countries



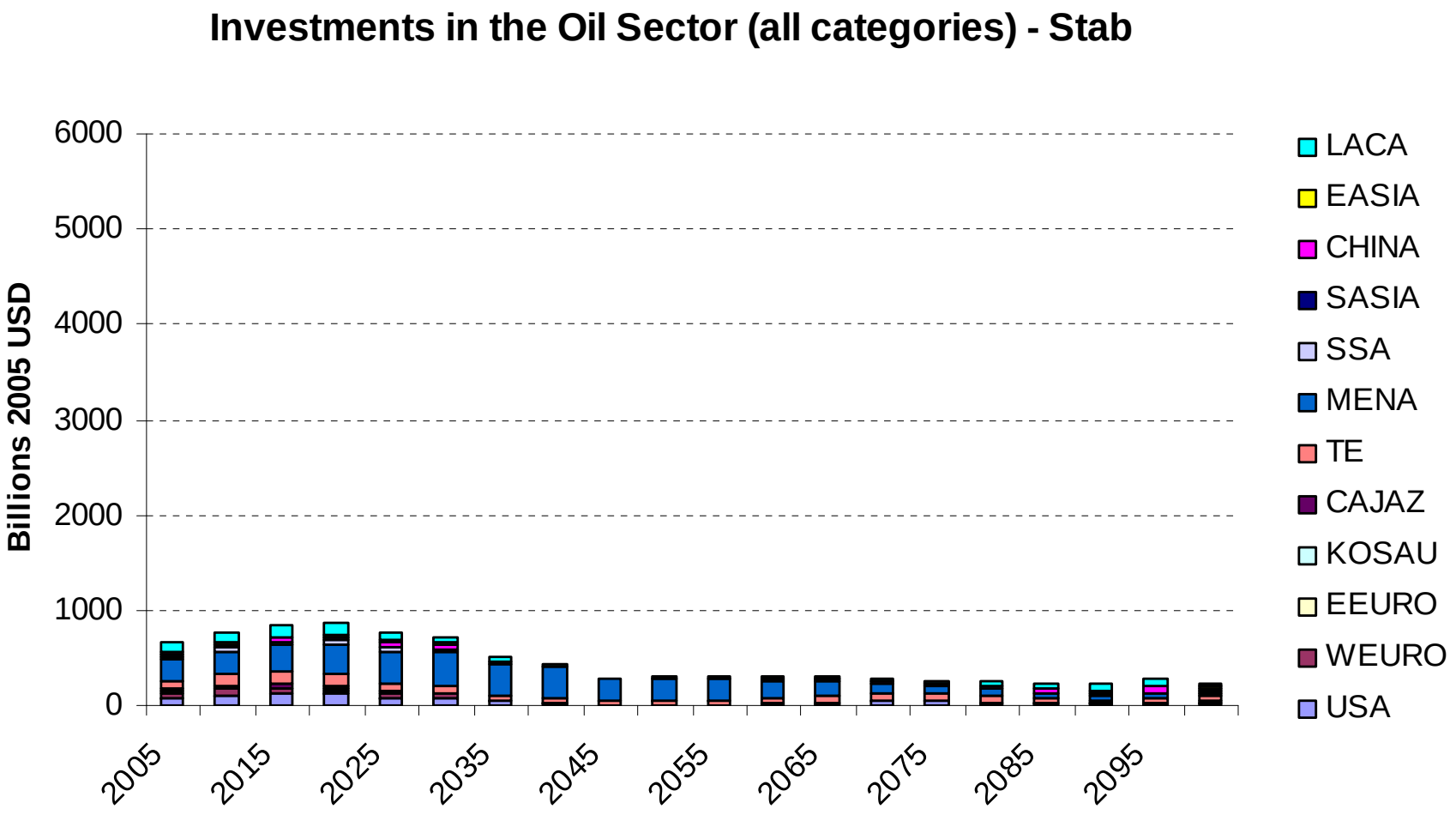






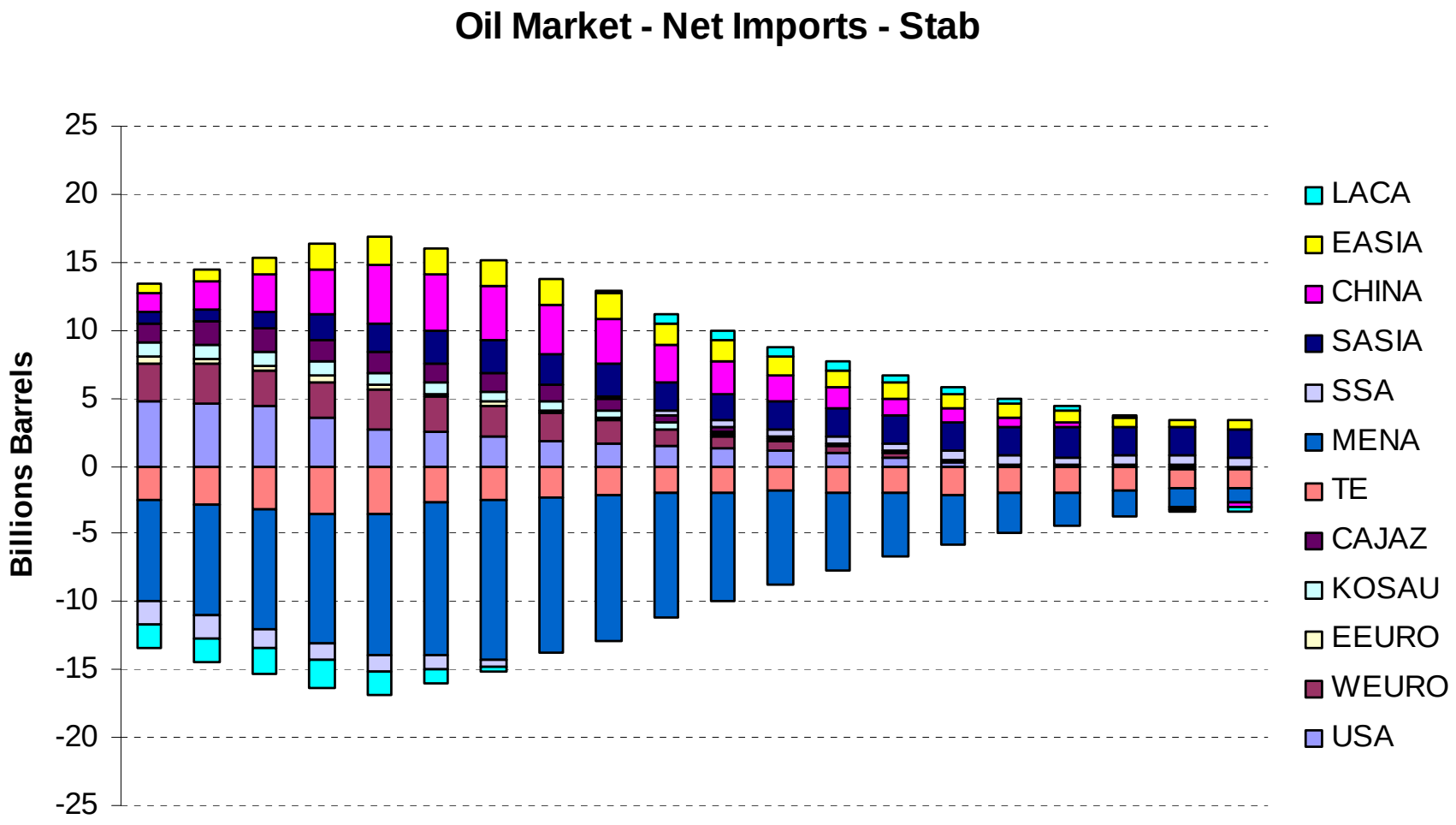
Non conventional oil is not produced

4- Results: Stab



Investments are decreasing over time from 2020

4- Results: Stab



TE and MENA are the main exporter countries

SASIA is the main importer at the end of the century

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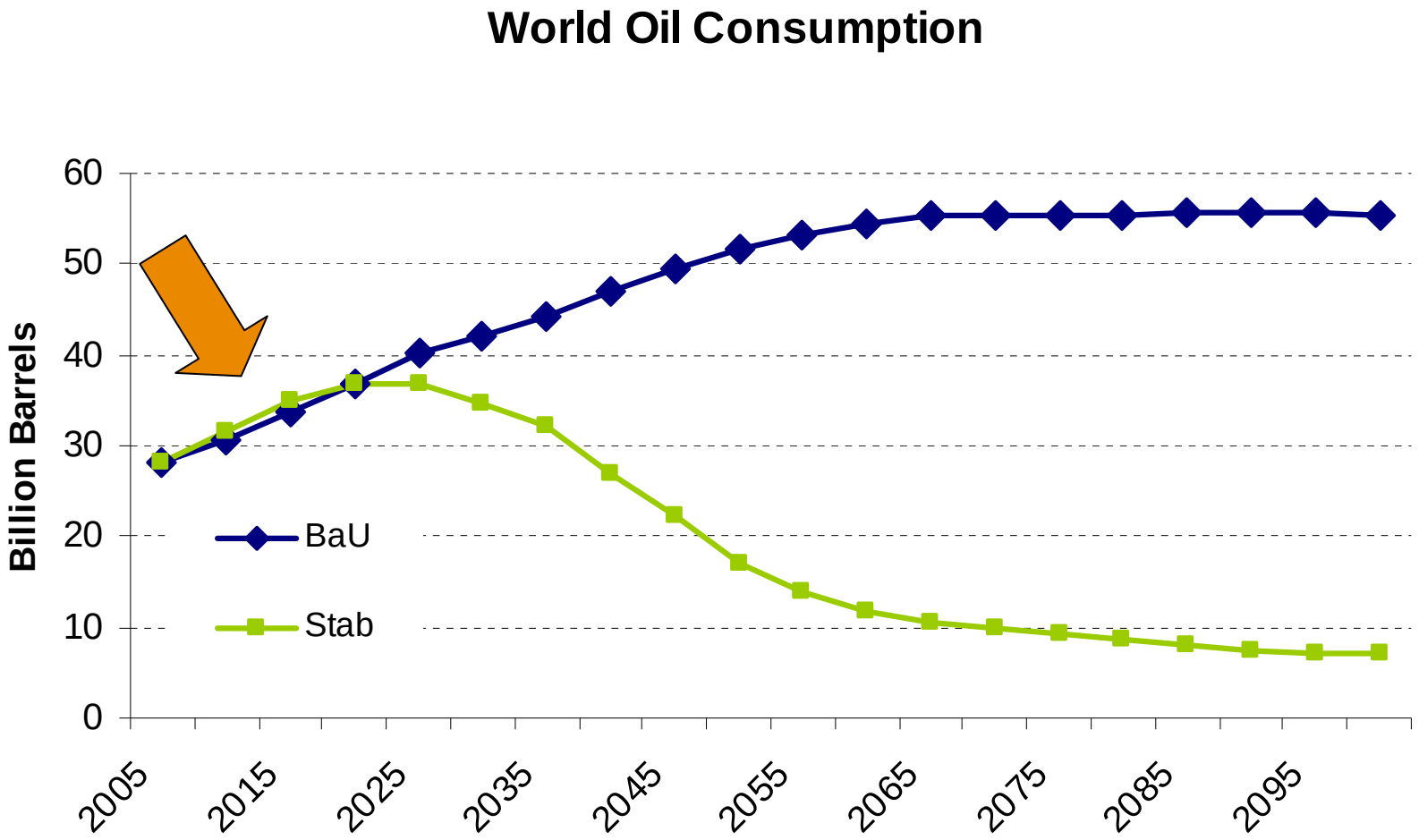
Comparison: BaU and Stab

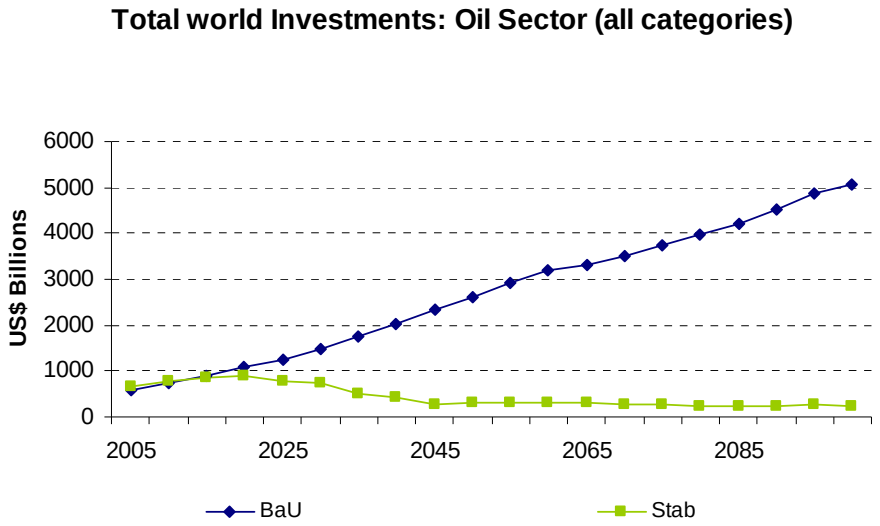
4- Results: Comparison

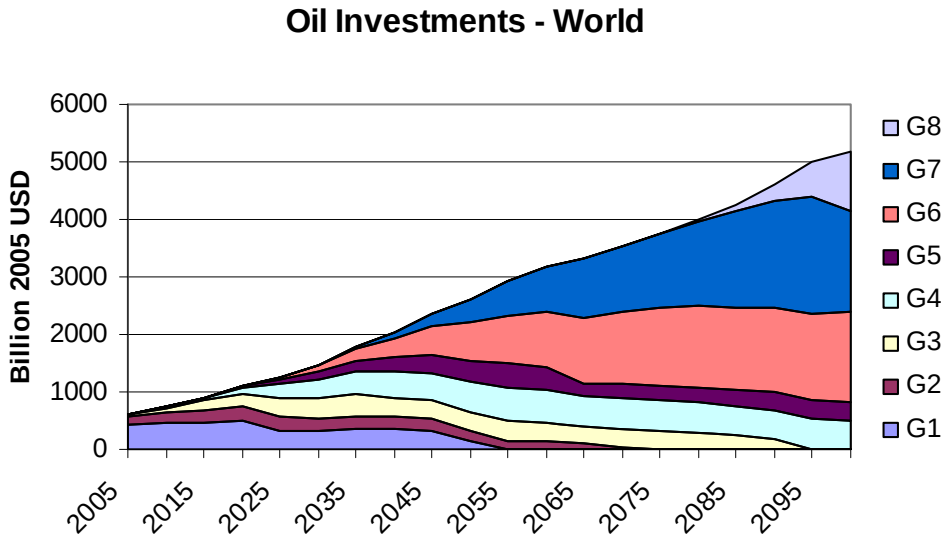


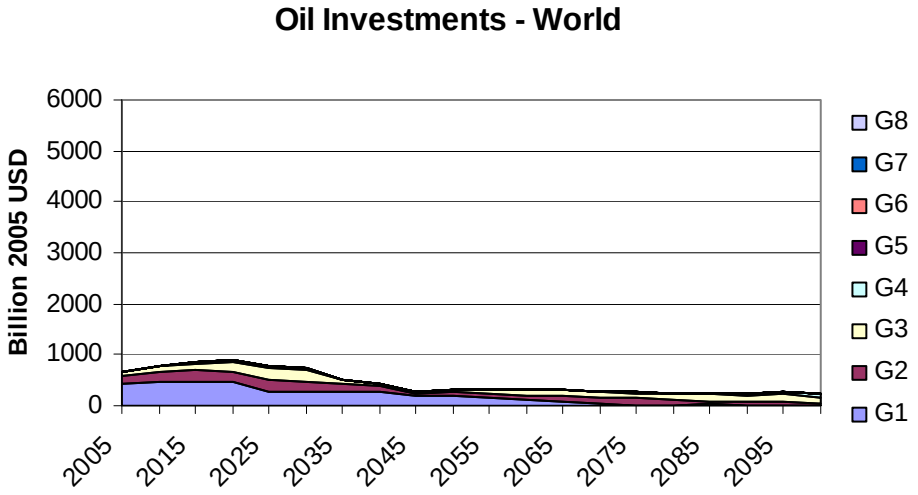
This result tend to conferm the theoretical model proposed by HOEL (2009)

4- Results: Comparison

How will investment decisions be affected when a cap on emissions is imposed throughout the century?

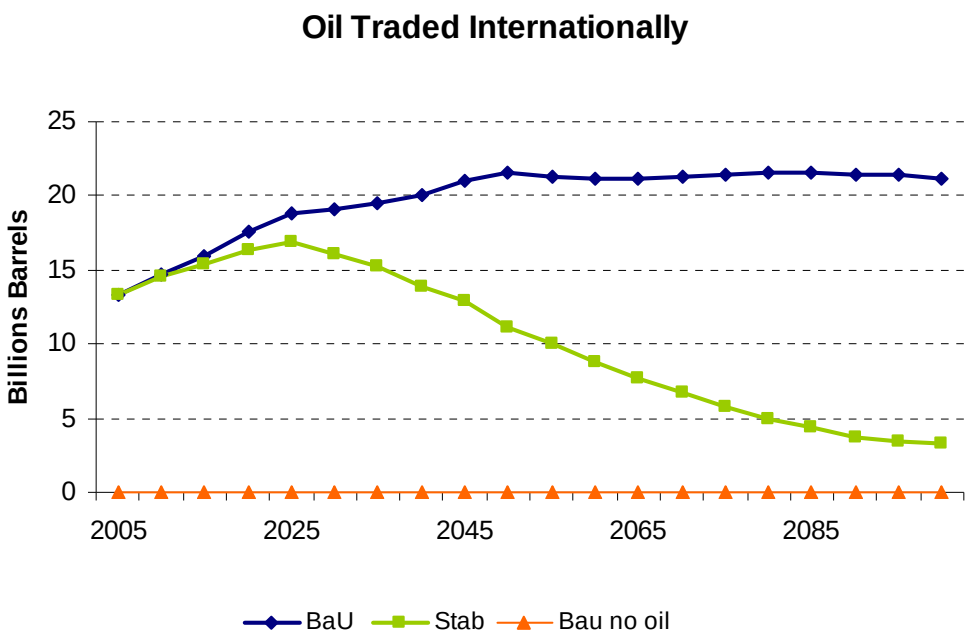


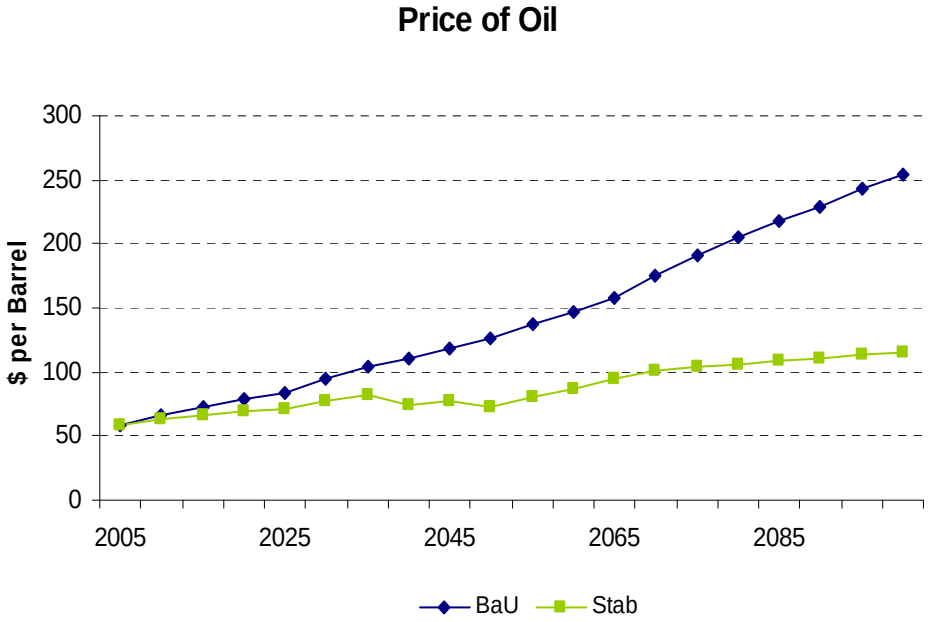




4- Results: Comparison

How will these investments decisions shape oil supply and how will they affect international trade of oil and oil price?





International trade of oil is mainly driven by oil consumption

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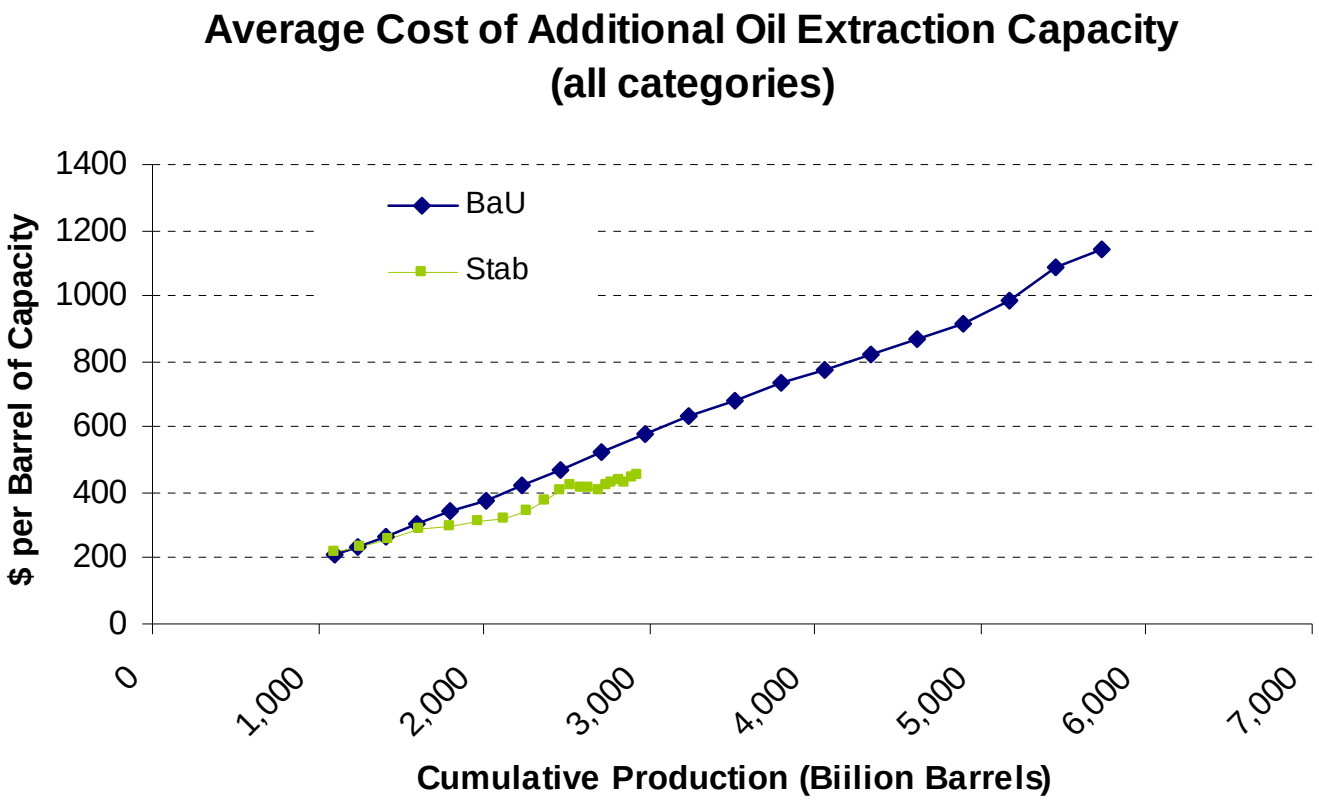
4- Results: Comparison



The cost of additional oil extraction capacity is lower in the stabilization scenario.

Under climate policy, cumulative oil production is about one half if compared to the BaU

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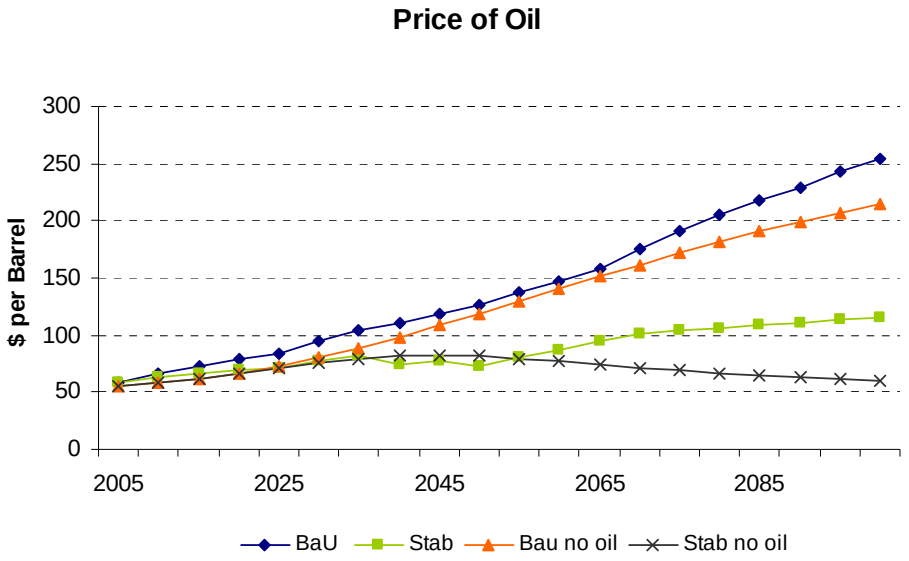
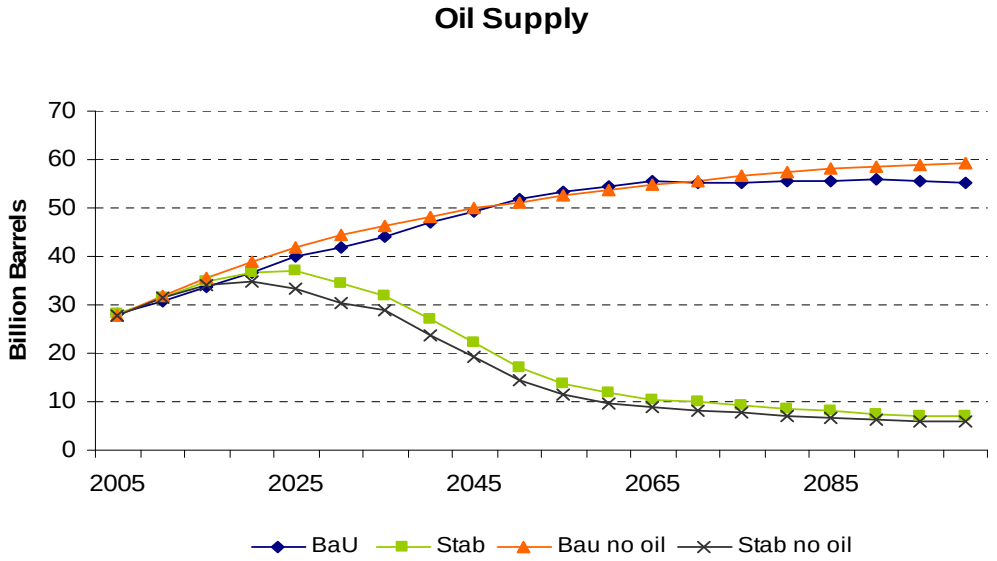
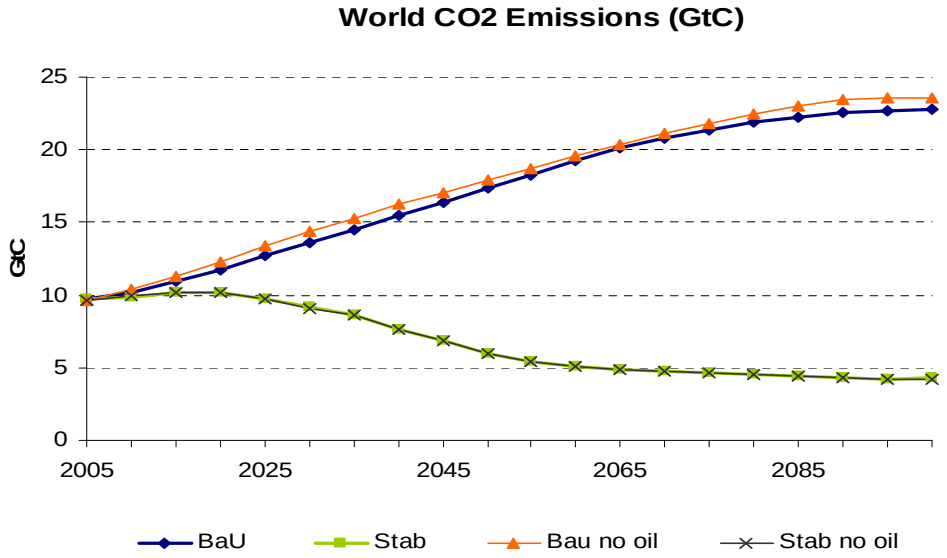
4- Comparison with previous version of the model







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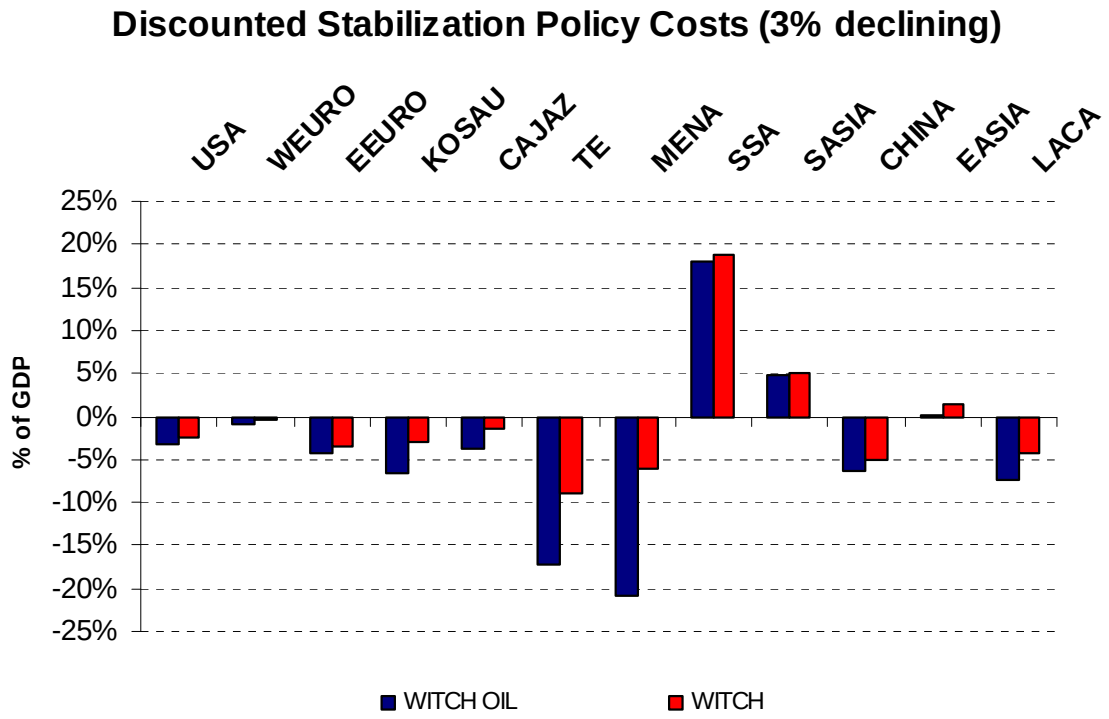
4- Results: Comparison

World

	2005	2025	2045	2065	2085	2105
Oil GDP (% of total GDP)						
BaU	2.1%	2.3%	2.3%	2.4%	2.4%	2.4%
Stab	2.1%	1.8%	0.7%	0.3%	0.2%	0.5%
Oil Investments (%of total Investments)						
BaU	6.9%	7.7%	8.9%	8.7%	8.4%	8.8%
Stab	7.5%	4.9%	1.2%	0.9%	0.5%	0.4%

4- Results: Comparison

To what degree will oil exporting countries be able to re-structure their production activities, to counter-act the threat to their economies, that a low-carbon world will poses ?



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Conclusion

Introduction of a detailed description of the oil sector does not change global mitigation costs significantly but regional costs do vary greatly.

The value of oil traded decrease significantly in a climate policy regime.

Oil investments decrease significantly

Oil-exporting countries bear costs twice as large if compared to previous estimates.

When carbon emissions are constrained non conventional oil (grades 5 - 8) is not extracted.

THANK YOU!