STEVENS
INSTITUTE of TECHNOLOGY
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SADC & ECOWAS Fuel Exporting Optimization Plan

BIA 650 - Optimization & Process Analysis

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Content

1

Introduction

SADC & ECOWAS

Introduction

The Southern African Development Community (SADC) is an intergovernmental organization headquartered in Gaborone, Botswana. Its goal is to further socio-economic cooperation and integration as well as political and security cooperation among 16 southern African states.

The Economic Community of West African States is Known as a regional economic union of fifteen countries located in West Africa. The union was established on 28 May 1975, with the signing of the Treaty of Tagos. The state's goal of ECOWAS is to achieve "collective self-sufficiency" for its member states by creating a single large trading bloc by building a full economic and trading union.

Introduction

Angola
Botswana
Democratic Republic of Congo
Lesotho
Madagascar
Malawi
Mauritius
Mozambique
Namibia
Seychelles
South Africa
Swaziland
United Republic of Tanzania
Zambia
Zimbabwe

Benin
Burkina Faso
Cape Verde
Côte d'Ivoire
The Gambia
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Niger
Nigeria
Senegal
Sierra Leone
Togo

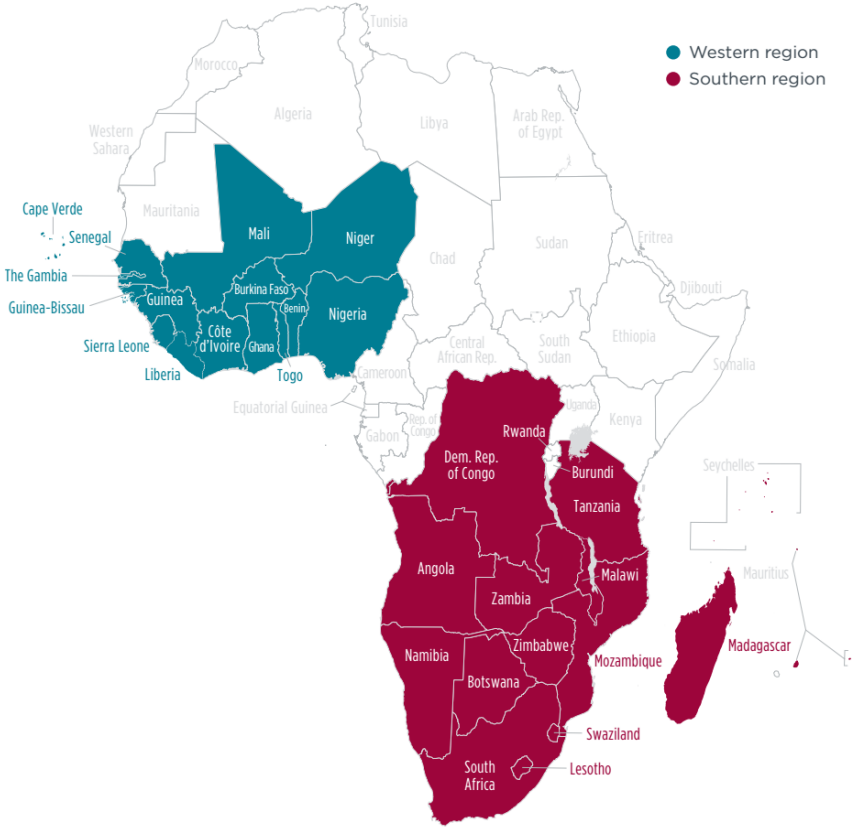

Figure 3. Map of regions and countries represented in this study.
Source: CITAC/ICCT (2016)

Background

- The consumption of refined products in both regions recorded 2 times growth since 2000.
- Only 4 countries has their own refinery. Other countries in these two region relies primarily on imports to meet their demand for refined products.
- Transportation within these countries is mostly dominated by road transportation.
- In The Energy Sector Plan (ESP), SADC & ECOWAS plan to build the pipelines within the countries to transport the Diesel and Gasoline in the following years.

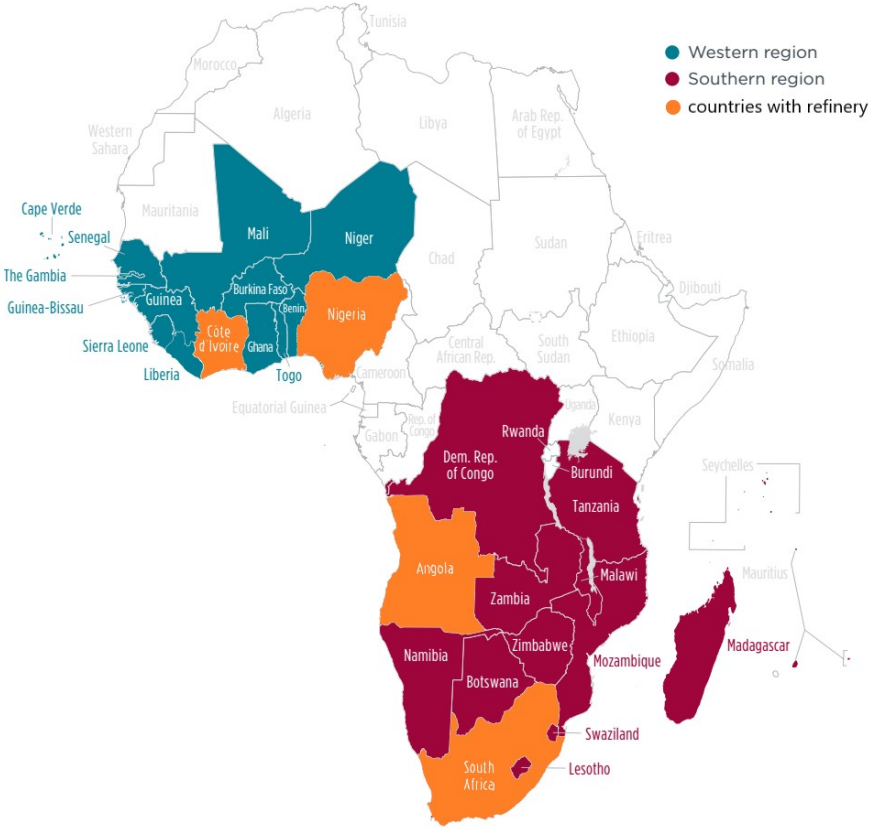

Figure 3. Map of regions and countries represented in this study.
Source: CITAC/ICCT (2016)

Project Goals

- Meet SADC & ECOWAS fuel **demands**
- Minimize transportation **cost**

(Transportation cost = **Total Freight** * The Cost per KM per BBL + Others)

Project Goals

- Meet SADC & ECOWAS fuel **demands**
- Minimize total **Freight**

(Total Freight=Total transportation distance(KM) * Total transportation weight(BBL))

2

Data Source & Interpretation

Data Source

- ★ SADC statistic service center

  http://www.sadc.int/information-services/sadc-statistics/

- ★ International Council on Clean Transportation(ICCT)

  http://www.theicct.org/

- ★ Transportation Distances

  https://www.distancefromto.net/countries.php

Data Scope

30 countries from
Southern & Western Africa

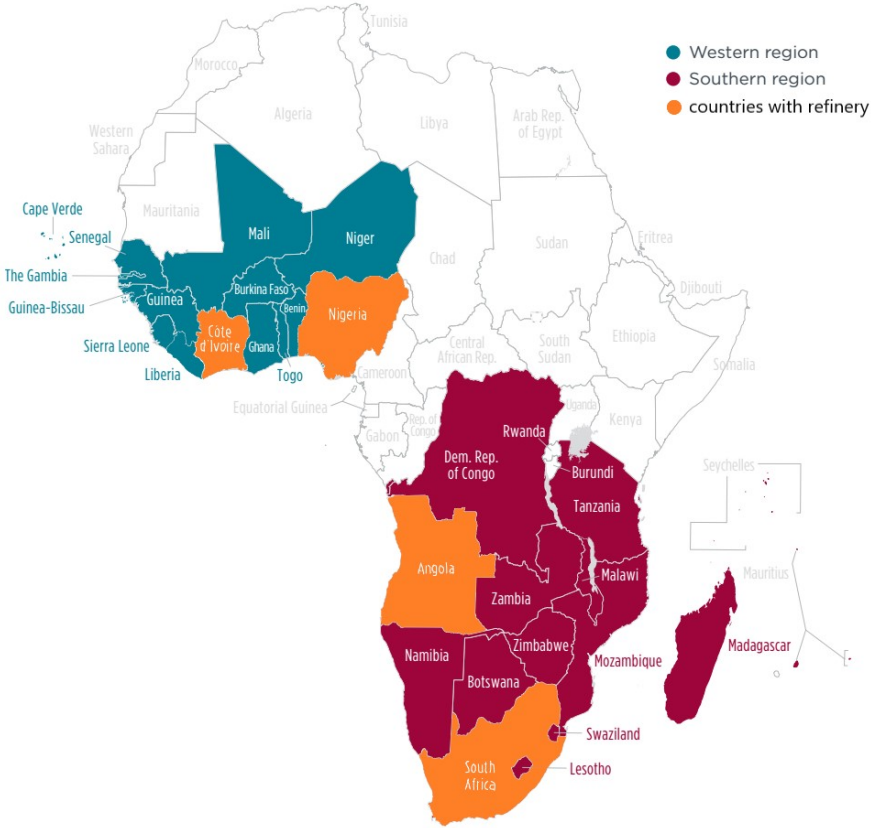

Figure 3. Map of regions and countries represented in this study.
Source: CITAC/ICCT (2016)

Data Interpretation

Fuel Consumption (bbl/day)

- Diesel
- Gasoline

Country	Diesel	Gasoline
Angola	75900	33300
Botswana	10300	8400
Democratic Republic of Congo	13400	7000
Lesotho	1800	1800
Madagascar	9100	2200
Malawi	3100	1800
Mauritius	5200	3300
Mozambique	14200	4600
Namibia	12400	7100
Seychelles	1200	400
South Africa	226100	198800
Swaziland	2800	2400
United Republic of Tanzania	31700	15100
Zambia	13700	6700
Zimbabwe	7000	3200
Benin	8200	3100
Burkina Faso	9500	5500
Cape Verde	2200	200
Côte d'Ivoire	17500	6600
The Gambia	1400	400
Ghana	35000	27100
Guinea	6600	6300
Guinea-Bissau	1000	300
Liberia	3300	2800
Mali	14000	2900
Niger	5800	3500
Nigeria	59000	298800
Senegal	18200	3500
Sierra Leone	4700	2300
Togo	2800	2100

Refinery Capacity(bbl/d)

Refineries Countries

- Angola
- South Africa
- Côte d'Ivoire
- Nigeria

Country	Refinery	Capacity
Angola	Sonaref	65000
South Africa	Chevref	100000
South Africa	Enref	122000
South Africa	Natref	108000
South Africa	Sapref	180000
South Africa	PetroSA GTL	45000
South Africa	Sasol CTL	160000
Zambia	Indeni	26000
Côte d'Ivoire	Société Ivoirienne de Rafnage (SIR)	68000
Côte d'Ivoire	Société Multinationale de Bitumes (SMB)*	10000
Ghana	Tema Oil Refinery (TOR)	45000
Niger	Société de Rafnage de Zinder (SORAZ)	20000
Nigeria	Kaduna Refining & Petrochemical Company (KRPC)	110000
Nigeria	Port Harcourt Refinery Company (PHRC)	210
Nigeria	Warri Refinery & Petrochemicals Company (WRPC)	125000
Senegal	Société Africaine de Rafnage (SAR)	27000

Transportation Distances(KM)

Country	Angola	South Africa	Côte d'Ivoire	Nigeria
Angola	0	2090.1	3329.06	2477.12
Botswana	1205.8	1175.9	4682.03	3908.65
Democratic Republic of Congo	1334.7	3386.3	3295.5	2059.36
Lesotho	2140.1	968.8	5492.7	4790.21
Madagascar	2140.1	3119.5	6453.77	5214.29
Malawi	461.9	2542.5	4976.49	3769.02
Mauritius	2975.5	2975.5	7567.6	6273.62
Mozambique	1878.4	2213.9	5370.06	4270.31
Namibia	1574	1043.1	4287.03	3723.58
Seychelles	4172.6	4893.1	6914.45	5415.96
South Africa	2090.1	0	5218.02	4919.42
Swaziland	2064.1	1384.4	5508.27	4666.55
United Republic of Tanzania	1947.2	3302.9	4749.36	3378.88
Zambia	1271.7	2164.1	4351.07	3257.1
Zimbabwe	1578.9	1753.6	4820	3851.58
Benin	2860	4955.22	887.88	699.28
Burkina Faso	3379.96	5438.31	681.51	1173.52
Cape Verde	5461.05	7191.45	2149.77	3536.59
Côte d'Ivoire	3329.06	5218.02	0	1575.84
The Gambia	4577.69	6383.99	1254.05	2661.82
Ghana	2987.35	4991.83	510.05	1075.14
Guinea	3853.98	5700.81	529.27	2019.05
Guinea-Bissau	4462.58	6234.34	1158.53	2628.24
Liberia	3605.56	5371.66	446.48	2018.38
Mali	4005.23	6084.97	1129.22	1665.09
Niger	3383.07	5593.1	1855.19	951.26
Nigeria	2477.12	4919.42	1575.84	0
Senegal	4634.03	6417.49	1243.11	2589.6
Sierra Leone	4051.81	5710.28	3837.27	2144.71
Togo	2903.99	4960.06	712.46	782.12

3

Optimization Model

Transportation Model

Key variables

Input variable	Fuel consumption per day, transportation distance between Africa countries, refinery capacity
Decision variable	Export plan
Objective to minimize	Total freight
Other output variables	Total in, total out, regional percentage , regional consumption per day
Constraints	Total in = Demand Total out <= Capacity Export plan >= 0

Model

Min $Total\ \text{freight} = \sum\sum a_{ij}x_{ij}$

s.t. $\sum x_{ij} = d_j$

$\sum x_{ij} \leq c_i$

$x_{ij} \geq 0$

Explaination

- x_{ij} is the export amount of refine country i to import country j.
- a_{ij} is the transportation distance from country i to country j.
- d_j is the demand for country j.
- c_i is the refinery capacity for country i.

All 12 refineries can’t satisfy all the demand ！

$$\mathrm{p}\ :\ Regional\ Percetage = \frac{Total\ refinery\ capacity}{Total\ fuel\ demand}$$

$$\mathrm{d_j} = \mathrm{p}D_\mathrm{j}$$

D_j is the total fuel consumption demand for coumtry j

Spreadsheet

Fuel Consumption(bbl/day)			
Country	Diesel	Gasoline	Regional consumption
Angola	75900	33300	93367
Botswana	10300	8400	15989
Democratic Republic of Congo	13400	7000	17442
Lesotho	1 800	1800	3078
Madagascar	9100	2200	9662
Malawi	3100	1800	4190
Mauritius	5200	3300	7268
Mozambique	14200	4600	16074
Namibia	12400	7100	16673
Seychelles	1200	400	1368
South Africa	226100	198800	363292
Swaziland	2 800	2400	4446
United Republic of Tanzania	31700	15100	40014
Zambia	13700	6700	17442
Zimbabwe	7000	3200	8721
Benin	8200	3100	9662
Burkina Faso	9500	5500	12825
Cape Verde	2200	200	2052
Côte d'Ivoire	17500	6600	20606
The Gambia	1400	400	1539
Ghana	35000	27100	53096
Guinea	6600	6300	11030
Guinea-Bissau	1000	300	1112
Liberia	3300	2800	5216
Mali	14000	2900	14450
Niger	5800	3500	7952
Nigeria	59000	298800	305921
Senegal	18200	3500	18554

Transportation Distance(km)				
Country	Angola	South Africa	Côte d'Ivoire	Nigeria
Angola	0	2090.1	3329.06	2477.12
Botswana	1205.8	1175.9	4682.03	3908.65
Democratic Republic of Congo	1334.7	3386.3	3295.5	2059.36
Lesotho	2140.1	968.8	5492.7	4790.21
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Cape Verde	5461.05	7191.45	2149.77	3536.59
Côte d'Ivoire	3329.06	5218.02	0	1575.84
The Gambia	4577.69	6383.99	1254.05	2661.82
Ghana	2987.35	4991.83	510.05	1075.14
Guinea	3853.98	5700.81	529.27	2019.05
Guinea-Bissau	4462.58	6234.34	1158.53	2628.24
Liberia	3605.56	5371.66	446.48	2018.38
Mali	4005.23	6084.97	1129.22	1665.09
Niger	3383.07	5593.1	1855.19	951.26
Nigeria	2477.12	4919.42	1575.84	0
Senegal	4634.03	6417.49	1243.11	2589.6

Refinery Capacity(bbl/day)		
Country	Refinery	Capacity
Angola	Sonaref	65000
South Afri	Chevref	100000
South Afri	Enref	122000
South Afri	Natref	108000
South Afri	Sapref	180000
South Afri	PetroSA GTL	45000
South Afri	Sasol CTL	160000
Côte d'Ivo	Société Ivoiri	68000
Côte d'Ivo	Société Multi	10000
Nigeria	Kaduna Refin	110000
Nigeria	Port Harcour	210
Nigeria	Warri Refine	125000
	Total	1093210

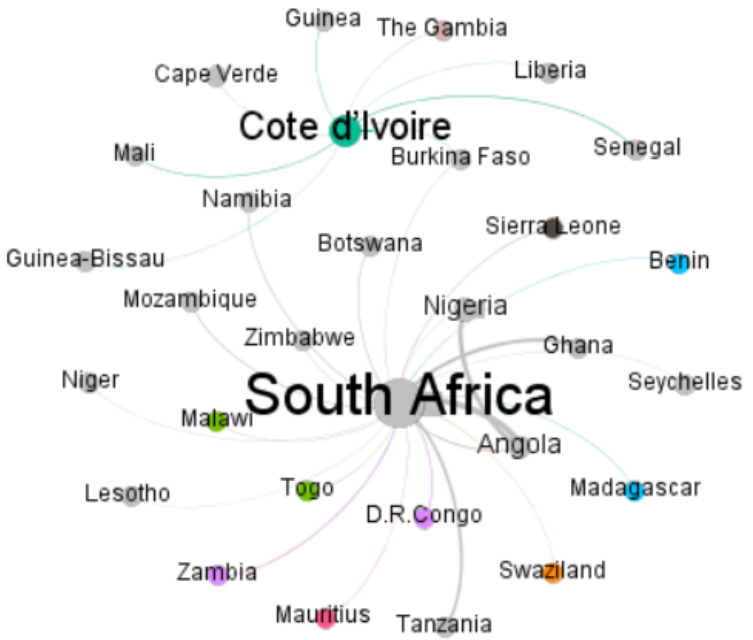
Export Plan(bbl/day)							
	Angola	South Africa	Côte d'Ivoire	Nigeria	Total in	=	Demand
Angola					0	=	93367
Botswana					0	=	15989
Democratic Republic of Congo					0	=	17442
Lesotho					0	=	3078
Madagascar					0	=	9662
Malawi					0	=	4190
Mauritius					0	=	7268
Mozambique					0	=	16074
Namibia					0	=	16673
Seychelles					0	=	1368
South Africa					0	=	363292
Swaziland					0	=	4446
United Republic of Tanzania					0	=	40014
Zambia					0	=	17442
Zimbabwe					0	=	8721
Benin					0	=	9662
Burkina Faso					0	=	12825
Cape Verde					0	=	2052
Côte d'Ivoire					0	=	20606
The Gambia					0	=	1539
Ghana					0	=	53096
Guinea					0	=	11030
Guinea-Bissau					0	=	1112
Liberia					0	=	5216
Mali					0	=	14450
Niger					0	=	7952
Nigeria					0	=	305921
Senegal					0	=	18554
Sierra Leone					0	=	5985
Togo					0	=	4190
Total out	0	0	0	0			
<=	<=	<=	<=	<=			
Capacity	65000	715000	78000	235210			

Solution

Export Plan(bbl/day)				
	Angola	South Africa	Côte d'Ivoire	Nigeria
Angola	0	93367	0	0
Botswana	0	15989	0	0
Democratic Republic of Congo	0	17442	0	0
Lesotho	0	3078	0	0
Madagascar	0	9662	0	0
Malawi	0	4190	0	0
Mauritius	0	7268	0	0
Mozambique	0	16074	0	0
Namibia	0	16673	0	0
Seychelles	0	1368	0	0
South Africa	0	363292	0	0
Swaziland	0	4446	0	0
United Republic of Tanzania	0	40014	0	0
Zambia	0	17442	0	0
Zimbabwe	0	8721	0	0
Benin	0	9662	0	0
Burkina Faso	0	9382	3444	0
Cape Verde	0	0	2052	0
Côte d'Ivoire	0	0	20606	0
The Gambia	0	0	1539	0
Ghana	0	53096	0	0
Guinea	0	0	11030	0
Guinea-Bissau	0	0	1112	0
Liberia	0	0	5216	0
Mali	0	0	14450	0
Niger	0	7952	0	0
Nigeria	65000	5711	0	235210
Senegal	0	0	18554	0
Sierra Leone	0	5985	0	0
Togo	0	4190	0	0
Total out	65000	715000	78000	235210
<=	<=	<=	<=	<=
Capacity	65000	715000	78000	235210

Regional Percetage	0.855005475

Objective to minimize	
Total freight	1299439019



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Sensitivity Analysis

Constraints

- Refinery **Capacity**
- SADC & ECOWAS fuel **Demands**

New Refinery Projects

Table 11. Refinery projects announced in Southern Africa as of 2016.

Country	Refinery	Refinery project
Angola	Lobito	New refinery proposed in Lobito.
South Africa	Natref	Plans confirmed for increased desulfurizatio and benzene extraction.
	Satref	Plans confirmed for increased desulfurizatio and benzene extraction.
Zambia	Indeni	Bitumen unit has been rehabilitated and is undergoing testing before re-commissioning

Table 12. Refinery projects announced in Western Africa as of 2016.

Country	Refinery	Refinery project
Côte d'Ivoire	Société Ivoirienne de Raffinage (SIR)	SIR is looking to add new desulfurization capacity for gasoline and diesel.
Ghana	Tema Oil Refinery (TOR)	Proposed new CDU, reformer, isomeriser, desulfurizer, hydrocracker, and bitumen unit.
Guinea	Kamsar (by Brahams Oil Refineries)*	New refinery expected to be built in Kamsar, with 10,000 bpd
Nigeria	Kaduna, Port-Harcourt, Warri, Dangote Industries refinery (Lagos)	Project to upgrade the refineries Dangote Industries has announced its intention to construct a new 650,000 b/d refinery on the outskirts of Lagos.
Senegal	Société Africaine de Raffinage (SAR)	Plans adopted to increase capacity and desulfurization

Source: ARA (2017b); CITAC/ICCT (2016); UNEP/CCAC (2016c)
*Official name of refinery not provided

Demand

➢Africa's demand for oil products is forecast to grow by over 3.1% per year from 2015 to 2030.

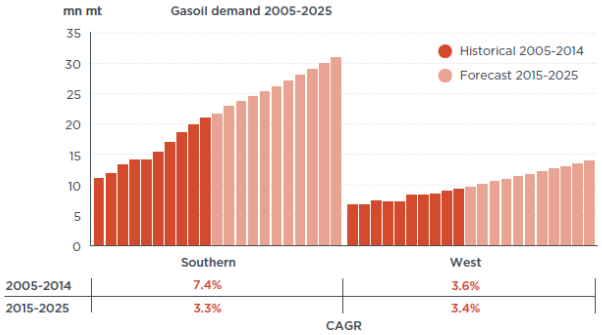


Figure 17. Historical and projected diesel demand in Southern and Western Africa, 2005–2025.
Source: CITAC/ICCT (2016)

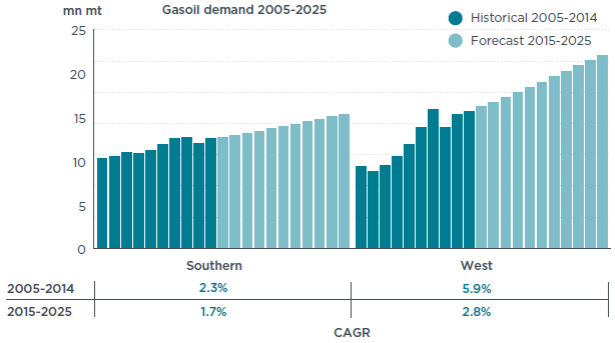
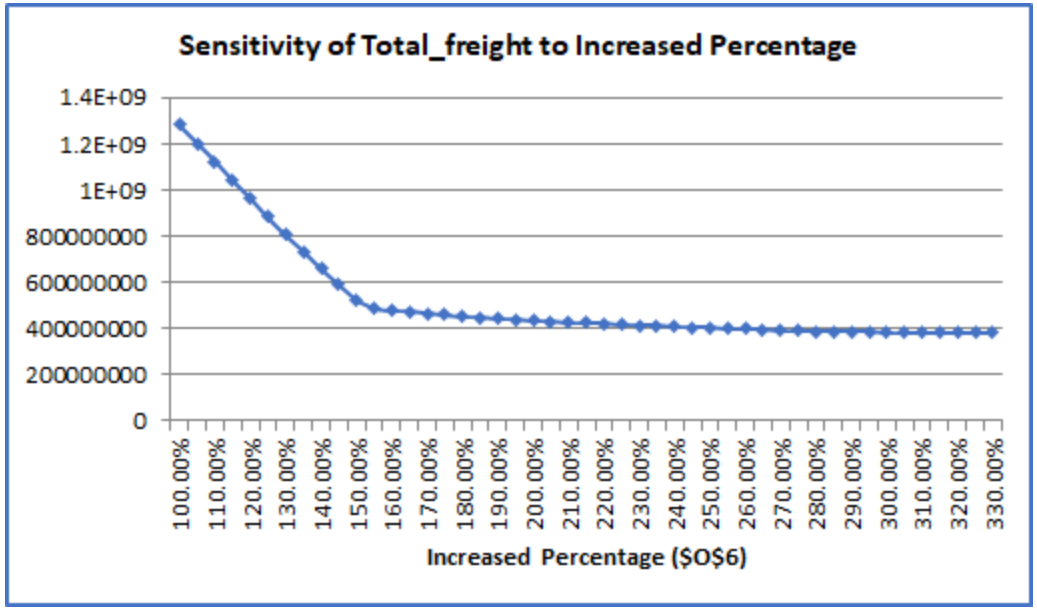


Figure 18. Historical and projected gasoline demand in Southern and Western Africa, 2005–2025.
Source: CITAC/ICCT (2016)

Refinery Capacity(bbl/day)		
Country	Refinery	Capacity
Angola	Sonaref	65000
South Africa	Chevref	100000
South Africa	Enref	122000
South Africa	Natref	108000
South Africa	Sapref	180000
South Africa	PetroSA GTL	45000
South Africa	Sasol CTL	160000
Côte d'Ivoire	Société Ivoi	68000
Côte d'Ivoire	Société Mul	10000
Nigeria	Kaduna Refi	110000
Nigeria	Port Harcou	210
Nigeria	Warri Refine	125000
	Total	1093210

Refinery Capacity(bbl/day)				
Country	Refinery	Capacity	Increased Percentage	Increased Capacity
Angola	Sonaref	65000	100.00%	65000
South Africa	Chevref	100000		100000
South Africa	Enref	122000		122000
South Africa	Natref	108000		108000
South Africa	Sapref	180000		180000
South Africa	PetroSA GTL	45000		45000
South Africa	Sasol CTL	160000		160000
Côte d'Ivoire	Société Ivoi	68000		68000
Côte d'Ivoire	Société Mul	10000		10000
Nigeria	Kaduna Refi	110000		110000
Nigeria	Port Harcou	210		210
Nigeria	Warri Refine	125000		125000
	Total	1093210		1093210

Freight to Capacity



315.00%	381910355
320.00%	381506798
325.00%	381506798

Two-way Table

demand percentage (cell B38) values along side, increased (cell O6) values along top, output cell in corner											
Total_freight	100.00%	130.00%	160.00%	190.00%	220.00%	250.00%	280.00%	310.00%	340.00%	370.00%	400.00%
85.00%	1281956257.3	809306148.9	478920357.7	444792932.6	420703017.0	403008029.7	388678136.5	382478129.0	381506797.6	381506797.6	381506797.6
90.00%	Not feasible	976104101.4	540122198.8	481090205.3	454369846.8	435244685.3	419295503.5	408424004.4	403948378.7	403948378.7	403948378.7
95.00%	Not feasible	1142976497.3	687725935.5	521022818.9	490382906.7	467576171.6	450079529.8	435785954.8	428327719.4	426389959.7	426389959.7
100.00%	Not feasible	1310068711.3	845284891.1	561143006.6	526395923.8	500561858.0	482316146.9	466407237.3	454773651.9	449373083.5	448831514.0
105.00%	Not feasible	1478382741.3	1008843100.1	610450483.3	563217620.5	535972880.9	514552841.0	497151043.7	482897725.0	474677398.5	471273121.8
110.00%	Not feasible	1649079467.3	1175686027.8	729281472.7	603289562.6	571985898.0	547434997.4	529387660.9	513519007.5	501123331.0	495105289.1
115.00%	Not feasible	Not feasible	1342558224.8	884965340.5	643365671.0	607998915.0	581562748.2	561624278.0	544222480.8	530009422.3	521027014.5
120.00%	Not feasible	Not feasible	1509430819.6	1044047338.0	684357047.3	645484364.2	617575851.1	594308152.0	576459174.8	560630777.8	547473010.0
125.00%	Not feasible	Not feasible	1677114325.1	1208395558.2	772673039.8	685556306.3	653588868.2	627293838.4	608695792.0	591293994.7	577121192.5
130.00%	Not feasible	Not feasible	1845451584.4	1375268153.1	926117050.5	725628343.8	689710640.5	663165825.3	641181306.5	623530688.7	607742548.0
135.00%	Not feasible	Not feasible	2016202476.1	1542140350.1	1082207757.3	765987788.3	727751077.7	699178842.4	674166993.0	655767305.9	638365508.7
140.00%	Not feasible	Not feasible	Not feasible	1709012547.1	1242809577.9	833625947.4	767823019.8	735191859.4	708755713.6	688054382.4	670602125.8
145.00%	Not feasible	Not feasible	Not feasible	1875885142.0	1407977869.5	967748239.0	807895057.3	771451558.5	744768816.5	721040147.5	702838819.8
150.00%	Not feasible	Not feasible	Not feasible	2044159938.9	1574850066.5	1123349215.3	848210421.7	810017821.4	780781833.6	754345687.8	735075437.0
155.00%	Not feasible	Not feasible	Not feasible	2212520427.5	1741722661.4	1280596134.7	903954259.8	850089859.0	816794936.5	790358790.7	767913302.1
160.00%	Not feasible	Not feasible	Not feasible	2383325485.0	1908594858.4	1441572201.9	1009708416.7	890161801.0	853192476.5	826371807.8	800898988.5

Decision variables and constraints							
Export Plan(bbl/day)							
	Angola	South Africa	Côte d'Ivoire	Nigeria	Total in	=	Demand
Angola	92820	0	0	0	92820	=	92820
Botswana	0	15895	0	0	15895	=	15895
Democratic Republic of Congo	17340	0	0	0	17340	=	17340
Lesotho	0	3060	0	0	3060	=	3060
Madagascar	9605	0	0	0	9605	=	9605
Malawi	4165	0	0	0	4165	=	4165
Mauritius	940	6285	0	0	7225	=	7225
Mozambique	15980	0	0	0	15980	=	15980
Namibia	0	16575	0	0	16575	=	16575
Seychelles	1360	0	0	0	1360	=	1360
South Africa	0	361165	0	0	361165	=	361165
Swaziland	0	4420	0	0	4420	=	4420
United Republic of Tanzania	39780	0	0	0	39780	=	39780
Zambia	17340	0	0	0	17340	=	17340
Zimbabwe	8670	0	0	0	8670	=	8670
Benin	0	0	0	9605	9605	=	9605
Burkina Faso	0	0	12750	0	12750	=	12750
Cape Verde	0	0	2040	0	2040	=	2040
Côte d'Ivoire	0	0	20485	0	20485	=	20485
The Gambia	0	0	1530	0	1530	=	1530
Ghana	0	0	52785	0	52785	=	52785
Guinea	0	0	10965	0	10965	=	10965
Guinea-Bissau	0	0	1105	0	1105	=	1105
Liberia	0	0	5185	0	5185	=	5185
Mali	0	0	14365	0	14365	=	14365
Niger	0	0	0	7905	7905	=	7905
Nigeria	0	0	0	304130	304130	=	304130
Senegal	0	0	18445	0	18445	=	18445
Sierra Leone	0	0	0	5950	5950	=	5950
Togo	0	0	4165	0	4165	=	4165
Total out	208000	407400	143820	327590			
<=	<=	<=	<=	<=			
Capacity	208000	2288000	249600	752672			

- ➢320% Capacity increased percentage
- ➢ 85% Demand

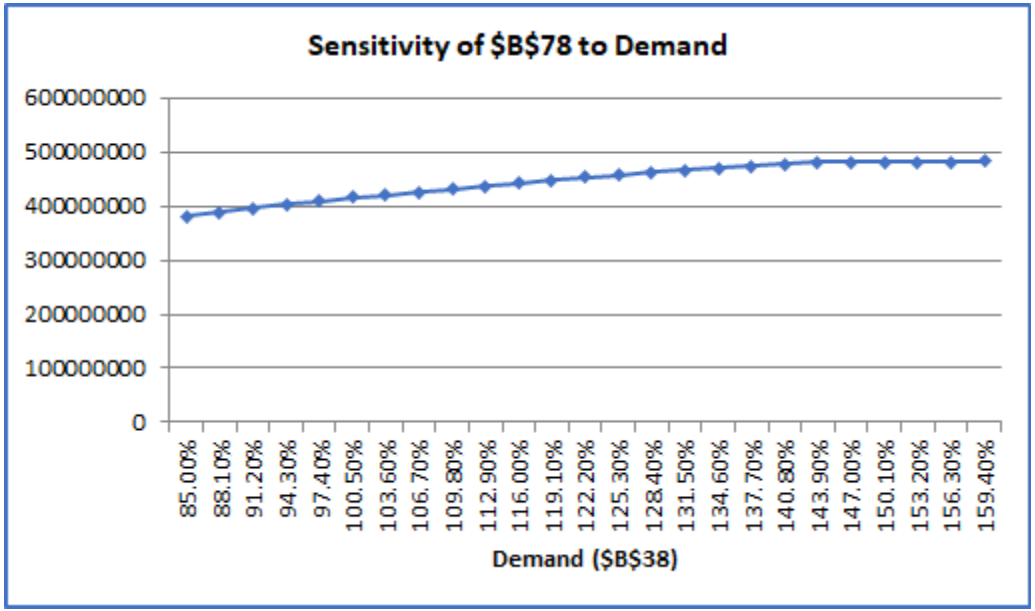
Extremum Model

- Sufficient Capacity
- Any Demand

Decision variables and constraints						
Export Plan(bbl/day)						
	Angola	South Africa	Côte d'Ivoire	Nigeria	Total	constrains
Angola	1	0	0	0	1	= 1
Botswana	0	1	0	0	1	= 1
Democratic Republic of Congo	1	0	0	0	1	= 1
Lesotho	0	1	0	0	1	= 1
Madagascar	1	0	0	0	1	= 1
Malawi	1	0	0	0	1	= 1
Mauritius	1	0	0	0	1	= 1
Mozambique	1	0	0	0	1	= 1
Namibia	0	1	0	0	1	= 1
Seychelles	1	0	0	0	1	= 1
South Africa	0	1	0	0	1	= 1
Swaziland	0	1	0	0	1	= 1
United Republic of Tanzania	1	0	0	0	1	= 1
Zambia	1	0	0	0	1	= 1
Zimbabwe	1	0	0	0	1	= 1
Benin	0	0	0	1	1	= 1
Burkina Faso	0	0	1	0	1	= 1
Cape Verde	0	0	1	0	1	= 1
Côte d'Ivoire	0	0	1	0	1	= 1
The Gambia	0	0	1	0	1	= 1
Ghana	0	0	1	0	1	= 1
Guinea	0	0	1	0	1	= 1
Guinea-Bissau	0	0	1	0	1	= 1
Liberia	0	0	1	0	1	= 1
Mali	0	0	1	0	1	= 1
Niger	0	0	0	1	1	= 1
Nigeria	0	0	0	1	1	= 1
Senegal	0	0	1	0	1	= 1
Sierra Leone	0	0	0	1	1	= 1
Togo	0	0	1	0	1	= 1

Extremum to Demand

Demand	Total Freight
85.00%	381506797.6
88.10%	388600867.2
91.20%	395694923.1
94.30%	402788992.7
97.40%	409400718.3
100.50%	415828235.7
103.60%	421121363.6
106.70%	426414491.4
109.80%	431707619.3
112.90%	437000747.2
116.00%	442293854.7
119.10%	447586982.5
122.20%	452880110.4
125.30%	457834574.2
128.40%	462378024.5
131.50%	466826114.6
134.60%	470525486
137.70%	474224871.6
140.80%	477924257.2
143.90%	481623642.8
147.00%	482142575
150.10%	482212737.6
153.20%	482282900.3
156.30%	482353062.7
159.40%	482423225.3



5

Conclusion & Discussion

Limitations

Conclusion

- Arrange the export plan to meet demand
  - SADC and ECOWAS
- Growth rate: capacity > demand
- Further impaction
  - Fuel transportation framework development
  - Energy market
    - Intimate relationship with fuel market

Limitation

- Geotechnical challenges
- Interactive coordination
  - Governor, regulator, landowner, construction contractor
- Usage and Cost
  - Transportation, Regulation, Salary
- Unforeseen obstacles and Force majeure
  - Weather, Environment

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Thanks for listening.