



# SOLAR POWER FOR AFRICA



UNIVERSITY OF BOTSWANA

# MODELLING THE DRIVERS OF SOLAR TECHNOLOGY ADOPTION IN A DEVELOPING COUNTRY CONTEXT

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# **INTEREST: MODELING SOLAR TECHNOLOGY ADOPTION AS A COMPLEX DYNAMIC PROCESS**



**I'VE ALWAYS BEEN INTRIGUED BY THE SLOW  
UPTAKE OF SOLAR ENERGY TECHNOLOGY**

**AND WONDERED WHAT ITS DRIVERS ARE AND  
HOW THE UPTAKE OF SOLAR ENERGY  
TECHNOLOGY COULD BE MODELED IN A  
COUNTRY LIKE BOTSWANA.**

**HENCE THE INTEREST TO SHARE WITH YOU  
SOME GENERAL INFO  
ABOUT THE NEED FOR SOLAR ENERGY  
TECHNOLOGY ADOPTION, ITS DRIVERS, AND A  
SUGGESTED MODEL FRAMEWORK FOR ITS  
ACCELERATED ADOPTION.**



**IN THIS DISCUSSION,**

**SOLAR TECHNOLOGY ADOPTION DENOTES THE  
PROCESS**

**BY WHICH THERE IS AN INCREASED  
PENETRATION OF SOLAR ENERGY TECHNOLOGY  
DEMAND**

**(MEASURED IN ACTUAL MW POWER OR MONETARY  
INVESTMENTS ADDED TO INTS CAPACITY  
INVESTMENT)**

**++**

**CULTURE FOR ITS SUSTENANCE**



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# DRIVERS OF SOLAR TECHNOLOGY ADOPTION



**1. NEED**

**2. SOLAR RESOURCE ENDOWMENT**

**3. AWARENESS**



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# 1. NEED FOR SOLAR ENERGY TECHNOLOGY



**THE ELECTRICITY GENERATED AT THE MORUPULE POWER STATION CANNOT SUSTAIN CURRENT DEMAND.**



**RELIANCE ON MORE THAN 70% ELECTRICITY IMPORTS. THIS ENERGY INSECURITY COMPROMISES ECONOMIC STABILITY**



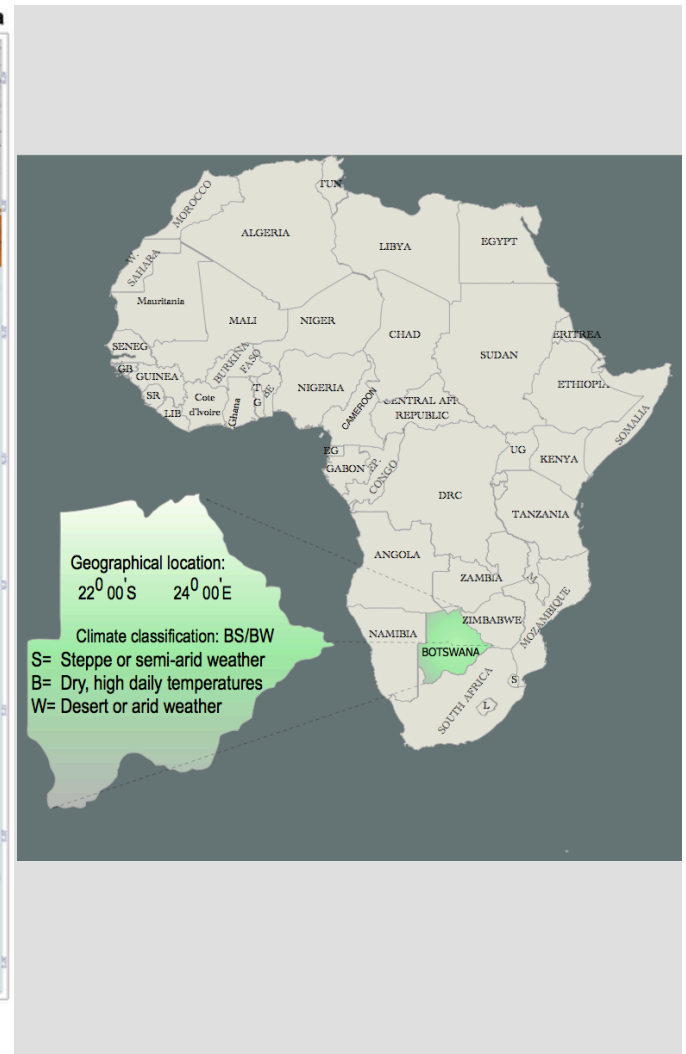
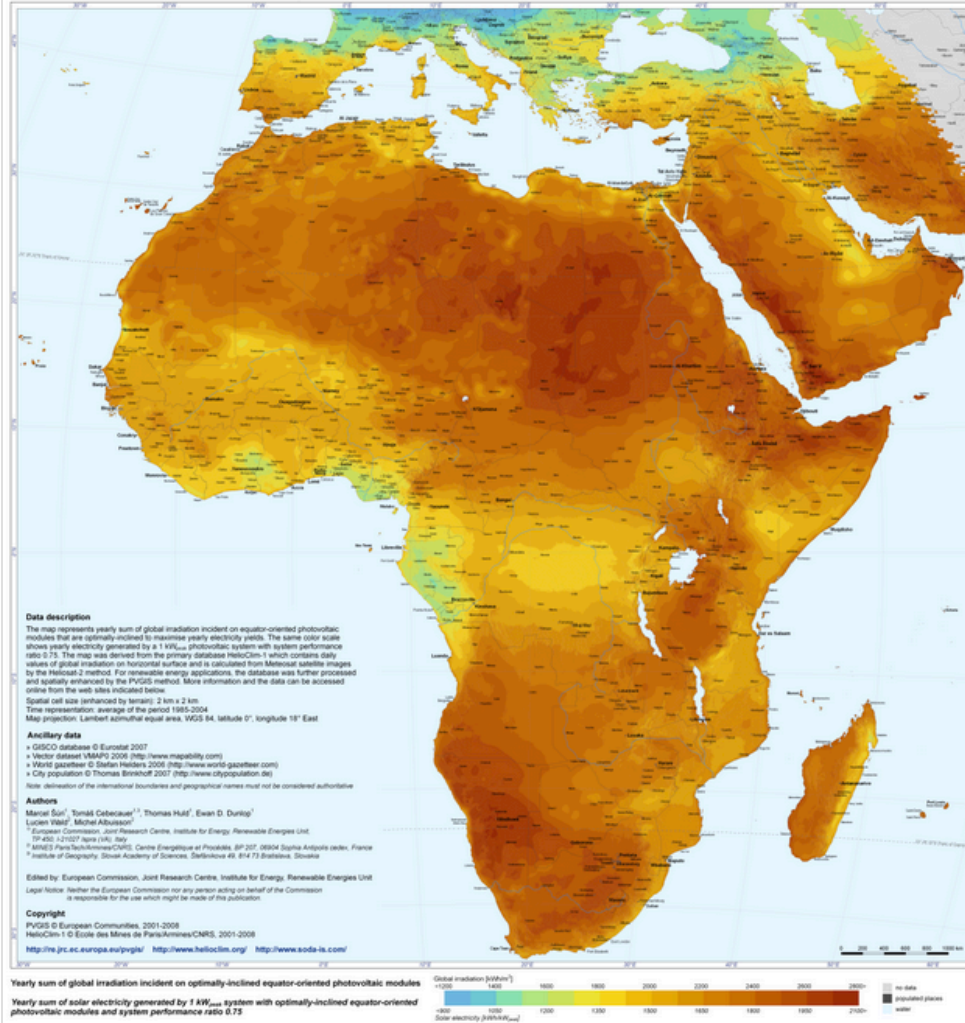
**BOTSWANA HAS MORE THAN 3200  
SUNSHINE HOURS ON AVERAGE  
IN A YEAR,  
WITH DNI LEVELS AROUND  
APPROXIMATELY 21MJ/m<sup>2</sup>**

**A CASE CAN BE MADE IN FAVOR OF SOLAR PV TECHNOLOGY BUSINESS.**

# 2. BACKGROUND - ENERGY ISSUES AND RELEVANT FACTS IN AFRICA



Photovoltaic Solar Electricity Potential in the Mediterranean Basin, Africa, and Southwest Asia

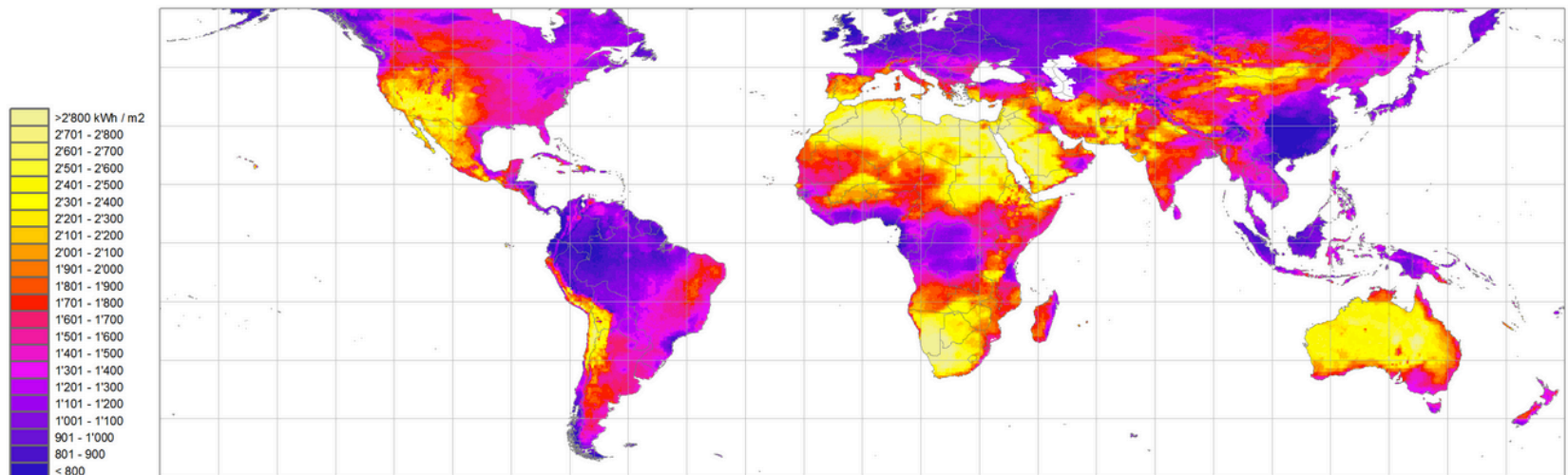






### 11. AFRICA IS ENDOWED WITH AN EXCELLENT SOLAR ENERGY POTENTIAL AS SHOWN BELOW.

Yearly sum of Direct Normal Irradiation (DNI)

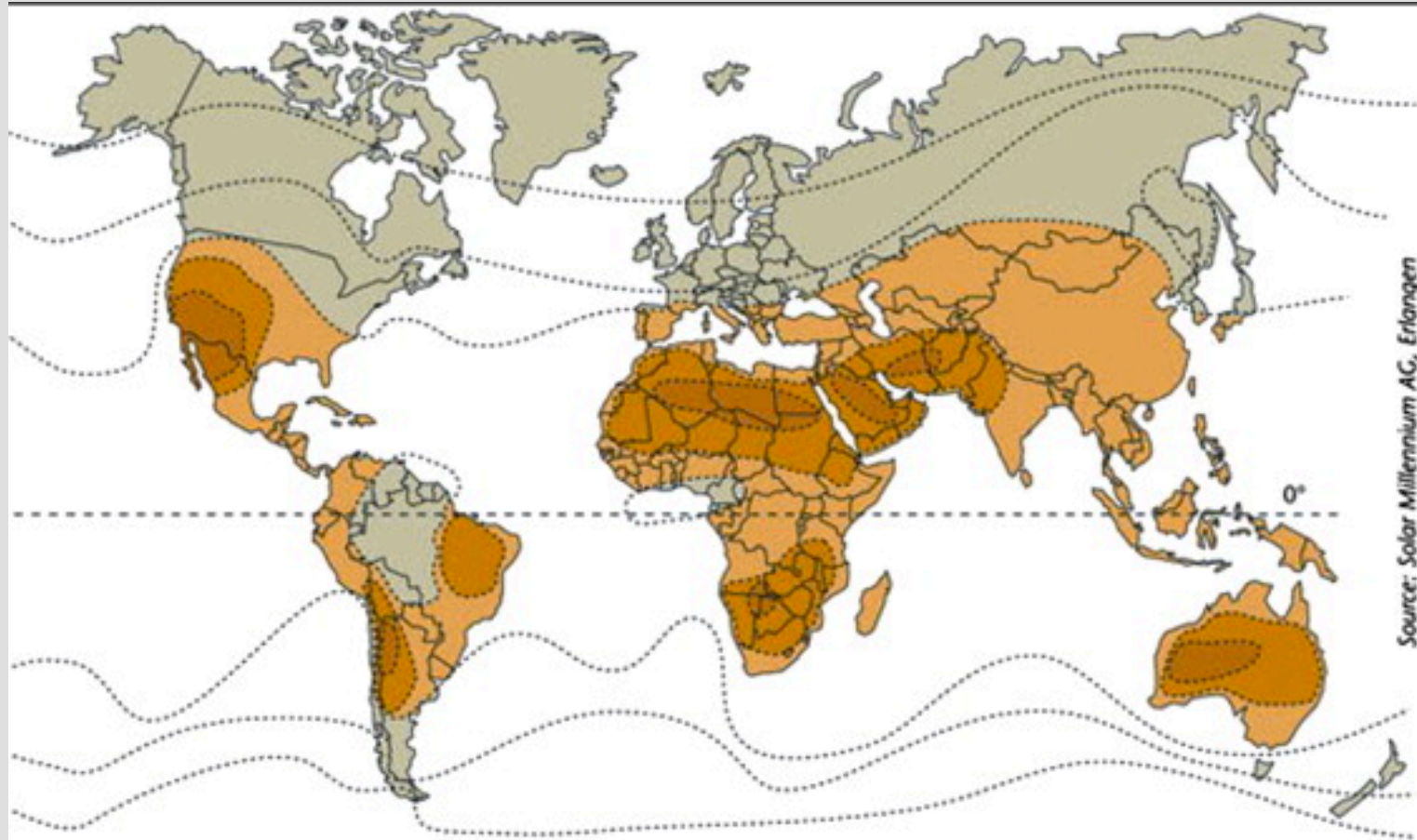


Source: Meeonorm 7.0 ([www.meteonorm.com](http://www.meteonorm.com)); uncertainty 15%  
Period: 1986 - 2005; grid cell size: 0.25°



## 2. BACKGROUND - ENERGY ISSUES AND RELEVANT FACTS IN AFRICA

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Source: Solar Millennium AG, Erlangen

Appropriate for solar thermal power plants:



excellent



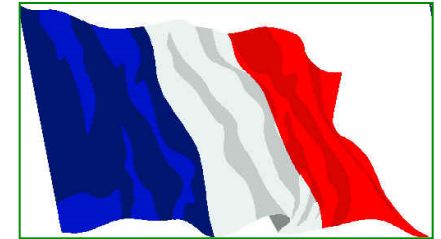
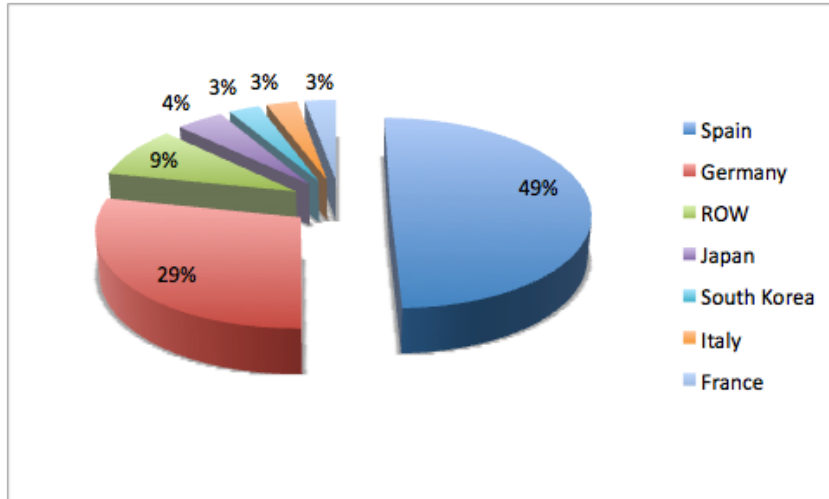
very good



good



not appropriate



**GLOBALLY, GERMANY & SPAIN:  
HAVE A COMBINED SHARE OF  
78% OF THE TOTAL GLOBAL  
SOLAR PV TECHNOLOGY  
PENETRATION (Martin, 2008)**

**REGIONALLY, LA RE' UNION:  
70,000 SWH IN 2006, +10000  
UNITS/YEAR TO 2008. FOR A  
POPULATION OF 800000,  
RATIO IS 1 SWH: 11 PEOPLE**

**GERMANY: ~1368 AVERAGE  
SUNSHINE HRS/YEAR!**

**LA RE' UNION: A REGIONAL SWH  
MARKET LEADER**



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# DESPITE THE AFOREMENTIONED....



**PV TECHNOLOGY  
PENETRATION IN  
RURAL AREAS  
REMAINS  
PRACTICALLY NON-  
EXISTENT**



**PV TECHNOLOGY  
ADOPTION IN  
URBAN AREAS  
IS EQUALLY  
VERY LOW**

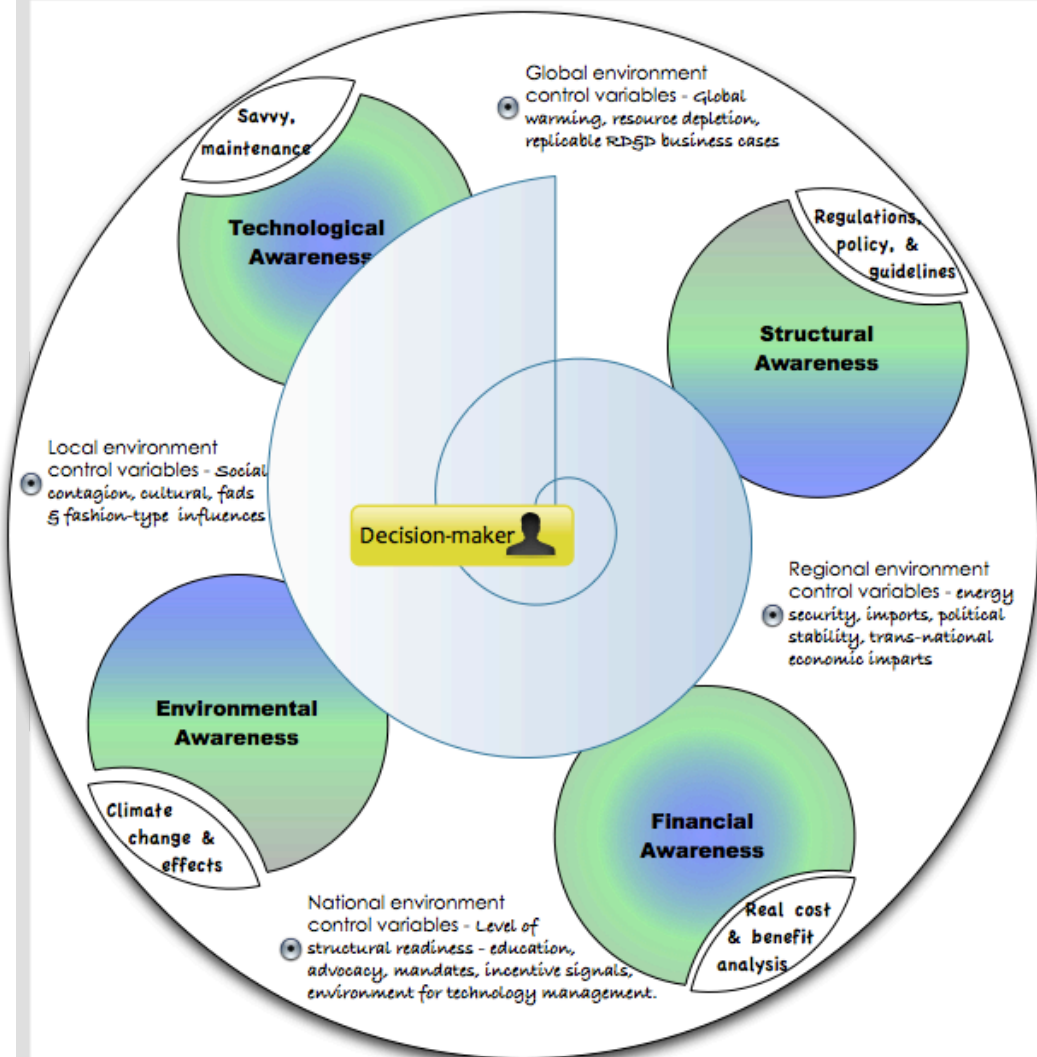
**NEEDED: A FRAMEWORK TO SUSTAIN SOLAR PV CHOICES.**



**A GENERAL LACK OF AWARENESS AND KNOW-HOW OF THE TECHNOLOGY AT ALL LEVELS OF DECISION-MAKING MAKES SOLAR TECHNOLOGY ADOPTION DIFFICULT DUE TO AWARENESS GAPS IN RELATION TO:**

- **UNDERSTANDING THE TECHNOLOGY ITSELF,**
- **SUPPORTIVE STRUCTURES AND THEIR READINESS,**
- **UNDERSTANDING FINANCIAL ISSUES INVOLVED,**
- **ENVIRONMENTAL ISSUES OF ENERGY SUPPLY & USE,**
- **UNDERSTANDING THE CONTROLLING GLOBAL/ REGIONAL/NATIONAL/ LOCAL ENVIRONMENT VARIABLES.**

**CONSIDER FOLLOWING SPINNING WHEEL METAPHOR:**



**THE POTENTIAL SOLAR TECHNOLOGY ADOPTER MUST BE AWARE OF AND SCAN THROUGH DYNAMICALLY-CHANGING ISSUES/FACTORS INFORMING HIS/HER DECISION WHILE TAKING INTO ACCOUNT GLOBAL, REGIONAL, NATIONAL, AND/OR LOCAL CONTROL VARIABLES.**

**THIS PROCESS IS PARTICULARLY DIFFICULT IN A DEVELOPING COUNTRY CONTEXT.**



# CONTEXTUALIZING RENEWABLE ENERGY TECHNOLOGY AWARENESS IN DEVELOPING COUNTRIES



## THE CONTROL VARIABLES THAT MAY IMPACT ON DECISION-MAKING RE CHOICES COULD BE:

### 1. GLOBAL:

- GLOBAL WARMING
- RESOURCE DEPLETION

### 2. REGIONAL:

- ENERGY IMPORTS
- POLITICAL STABILITY

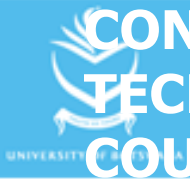
### 3. NATIONAL:

- ENERGY SECURITY
- ECONOMIC VULNERABILITIES

### 4. LOCAL:

- SOCIAL CULTURAL BELIEFS AND PRACTICES

**ISSUE IN DEVELOPING COUNTRY CONTEXT: MASTERY LEVEL OF THESE  
ISSUES IN RELATION TO THE NATIONAL-REGIONAL-GLOBAL REALITIES**



# CONTEXTUALIZING RENEWABLE ENERGY TECHNOLOGY AWARENESS IN DEVELOPING COUNTRIES



## **TECHNOLOGICAL AWARENESS:**

**TECHNOLOGY CAN BE GENERALLY INTIMIDATING. QUESTIONS ASKED ARE:**

- **HOW DOES IT WORK? WILL I MANAGE IT?**
- **DOES IT PERFORM AS WELL AS EXISTING CONVENTIONAL TECHNOLOGY?**
- **WHAT HAPPENS WHEN IT FAILS? WHO WILL UNDERTAKE MAINTENANCE?**
- **WHY HAS THE NEIGHBOR NOT ADOPTED IT?**

## **ISSUES IN DEVELOPING COUNTRY CONTEXT:**

**LACK OF EDUCATION MAY AGGRAVATE THE PROBLEM.**

**HOWEVER, EVEN THE EDUCATED ELITE HAVE GENERALLY NOT ADOPTED SOLAR TECHNOLOGIES. THE EASIEST RECOURSE HAS BEEN CONVENTIONAL COAL-BASED ELECTRICITY. HENCE THERE'S A LACK OF CHAMPIONS TO ACT AS ROLE MODELS AND HELP DISSEMINATE INFORMATION.**

**TECHNOLOGY KNOW-HOW AND AFTER-SALE SERVICE & MAINTENANCE ARE MAJOR CONCERNS.**





# CONTEXTUALIZING RENEWABLE ENERGY TECHNOLOGY AWARENESS IN DEVELOPING COUNTRIES



## ENVIRONMENTAL AWARENESS:

**REALITY OF GLOBAL WARMING HAS BROUGHT ABOUT:**

● **GLOBAL TEMPERATURE EXTREMES LEADING TO HURRICANES, FLOODING, DROUGHT**

● **SEASONAL CLIMATIC CHANGES WITH CONFUSED PATTERNS OF RAINFALL, LEADING TO UNPREDICTABLE CROP YIELDS AND FAMINE**

● **RISE IN TEMPERATURES MAKING REGIONS ONCE UNKNOWN FOR MALARIA TO BE NOW MALARIA-RIDDEN.**

## ISSUES IN DEVELOPING COUNTRY CONTEXT:

**THE INDIVIDUAL DECISION-MAKER CAN HARDLY RELATE BASIC SCIENTIFIC FACTS TO THE CONVENTIONAL ENERGY VIS-A-VIS RENEWABLE ENERGY DISCOURSE? HOW BEST CAN BASIC SCIENCE BE COMMUNICATED?**



# CONTEXTUALIZING RENEWABLE ENERGY TECHNOLOGY AWARENESS IN DEVELOPING COUNTRIES



## **FINANCIAL AWARENESS:**

**THE POTENTIAL ADOPTER BASES HIS DECISION ON AFFORDABILITY, NOW!**

- **UP-FRONT INVESTMENT COSTS ON SOLAR TECHNOLOGIES ARE HIGH,**
- **LONG-TERM FINANCIAL GAINS ARE RARELY ACCOUNTED FOR,**
- **LIFE-CYCLE COSTING IS UNKNOWN TO MANY,**
- **TRUE FINANCIAL GAINS NOT EASILY QUANTIFIED/UNDERSTOOD**

## **ISSUES IN DEVELOPING COUNTRY CONTEXT:**

**CONVENTIONAL ENERGY IS HIGHLY SUBSIDIZED, THEREBY DISTORTING THE MARKETS IN FAVOR OF CONVENTIONAL ENERGY SOURCES.**

**THERE IS A GENERAL LACK OF A CONCERTED EFFORT TO LEVEL THE PLAYING FIELD SO THAT SOLAR ENERGY WOULD BE MADE FINANCIALLY ATTRACTIVE**

**VIS-A-VIS CONVENTIONAL ENERGY (USUALLY BASED ON COAL)**



# CONTEXTUALIZING RENEWABLE ENERGY TECHNOLOGY AWARENESS IN DEVELOPING COUNTRIES



## STRUCTURAL READINESS:

### STRUCTURAL READINESS IN EDUCATION AND POLICY DESIGN ENSURES:

- ⊙ SUSTAINABLE LONG-TERM POLICY AND REGULATORY INSTRUMENTS,
- ⊙ DISSEMINATION OF KEY INFORMATION TO POTENTIAL ADOPTERS,
- ⊙ ADVOCACY FOR TECHNOLOGY THROUGH RD&D SHOW-CASE PROJECTS,
- ⊙ DESIGN OF EFFECTIVE INSTRUMENTS TO ATTRACT VENTURE CAPITAL,
- ⊙ REGULATION OF MARKET AND CREATION OF BUY-IN THRO INCENTIVES,
- ⊙ CREATION OF INCREASED AWARENESS FOR POTENTIAL INVESTORS,
- ⊙ THE AFFIRMATION OF DECISION-MAKING BY POTENTIAL ADOPTERS.

### STRUCTURAL AWARENESS ISSUES IN DEVELOPING COUNTRY CONTEXT:

- ⊙ CAPACITY BOTTLE-NECKS FOR EFFECTIVE POLICY DESIGN & OVERSIGHT,
- ⊙ ABSENCE OF INDEPENDENT REGULATORS FOR MARKET REFORM,
- ⊙ RELIANCE OF THE “OLD GUARD” TO DRIVE REQUISITE REFORM,
- ⊙ GENERAL BLACKOUT ON POLICY AND REGULATIONS MATTERS,
- ⊙ THIS RESULTS IN DISTORTED RANK-ORDERING OF ENERGY PRIORITIES.
- ⊙ RENEWABLE ENERGY REMAINS DISADVANTAGED IN ALL PLANNING.



# THE SPINNING WHEEL METAPHOR OF RENEWABLE ENERGY TECHNOLOGY ADOPTION



**THE SPINNING WHEEL METAPHOR SHOWS THE DIFFERENT DRIVERS THAT MUST BE TAKEN INTO ACCOUNT TO UNDERSTAND THE COMPLEX SOLAR ENERGY TECHNOLOGY ADOPTION PROCESS.**

**ONE INTEREST IN MODELING SUCH A PROCESS COULD BE A DESIRE TO QUANTIFY THE CUMULATIVE SOLAR TECHNOLOGY ADOPTION (MEASURED IN REAL MW ADDED OR ON INVESTED DOLLAR AMOUNT) AS WELL AS TO UNDERSTAND THE DYNAMICS OF A FRAMEWORK FOR SUSTAINING SUCH ADOPTIONS**

**I PROPOSE THAT THE AGENT-BASED MODELLING AND SIMULATION PARADIGM (ABMS) IS BEST SUITED TO CAPTURE THE COMPLEXITY OF SOLAR TECHNOLOGY ADOPTION.**



# **RATIONALE FOR ABMS FOR SOLAR TECHNOLOGY ADOPTION**



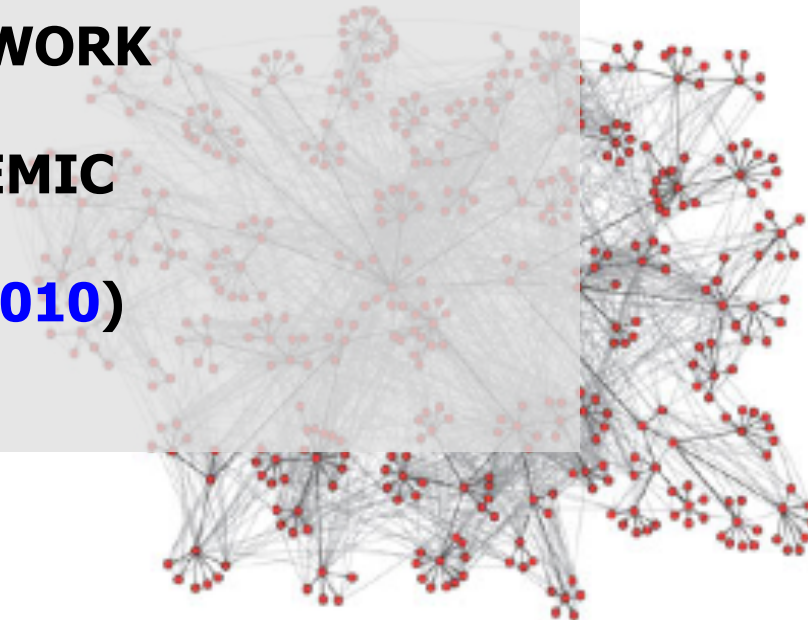
**SOLAR TECHNOLOGY ADOPTION  
PROCESS IS A COMPLEX PROCESS  
ACCOUNTING FOR THE  
ACTIONS AND ADAPTIVE  
FEEDBACKS OF MANY  
INTERACTING BUT DISPARATE  
ACTORS, EACH WITH THEIR OWN  
DECISION RULES GOVERNED AND  
GOVERNED BY UNIQUE FACTORS  
AND UTILITY FUNCTIONS  
MOTIVATING THEIR SOLAR  
TECHNOLOGY ADOPTION  
CHOICES.**

A complex network diagram with numerous nodes and connecting lines, rendered in yellow and orange, set against a solid orange background. The nodes are represented by small circles, and the lines are thin, creating a dense web of connections.

# 3. PROPOSED ABMS METHODOLOGY



**DIFFUSION**  
**IS A BEHAVIOR THAT CASCADES FROM**  
**NODE TO**  
**NODE IN A NETWORK**  
**LIKE AN EPIDEMIC**  
**(KLEINBERG, 2010)**





**SHALL COMPRISE OF A WEB OF NODES REPRESENTING INDIVIDUAL AGENTS WHERE THE LINKS BETWEEN THEM REPRESENT CHANNELS FOR THEIR INTERACTIONS.**



**THE COMMUNICATED INFORMATION SHALL BE THE DESIRED ADVOCACY FOR PV AWARENESS AND EVENTUAL ADOPTION**





**MICROLEVEL DECISIONS**

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**MACRO-LEVEL DIFFUSION**



**THE OBJECTIVE IS THEREFORE:**

**TO IMPLEMENT FROM BOTTOM-UP,  
A DYNAMICALLY-EVOLVING NETWORK OF PV ADOPTERS,  
BASED ON EMPIRICAL EVIDENCE OF  
WHAT THEY DEEM TO BE THE MAIN FACTORS MOTIVATING THEIR SOLAR  
PV TECHNOLOGY CHOICE-DECISIONS.**

**THIS IN TURN WILL HELP TO DESIGN  
AFFIRMATIVE POLICIES  
(DERIVED FROM THE PERSPECTIVE OF THE ENERGY END-USERS)  
THAT ARE  
CAPABLE OF SUSTAINING PV TECHNOLOGY CHOICE-DECISIONS.**

**FROM END-USER BEHAVIORS**

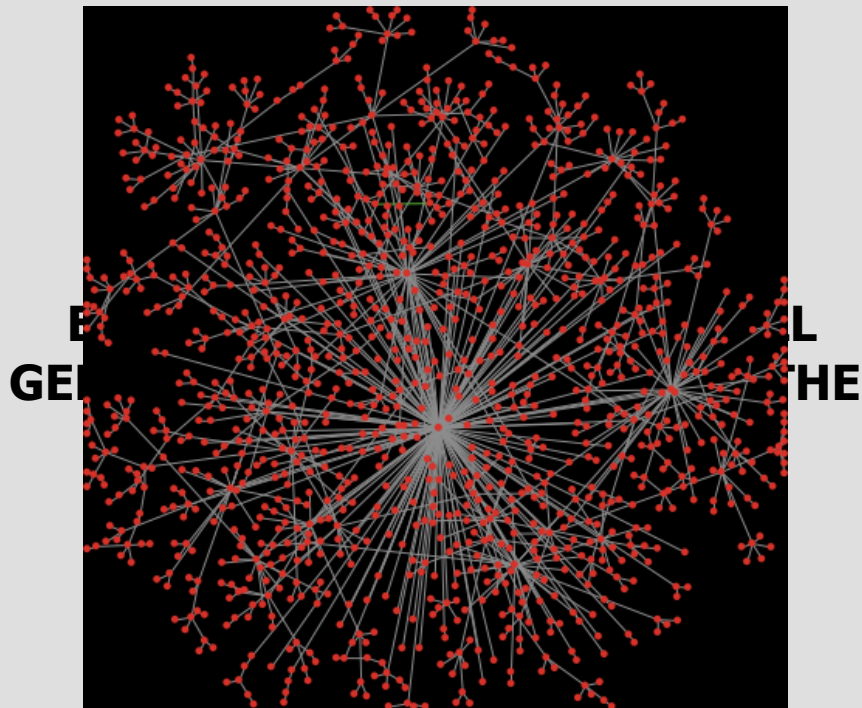


**TO DIFFUSION-GUIDING POLICY**



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# EXPECTED OUTCOME: A SCALE-FREE NETWORK WITH IDENTIFIABLE HUBS



**HUBS ARE THE WELL-CONNECTED AMONG ALL NODE AGENTS**

THE HUBS ARE ACCOUNTED FOR BY AN ADDITIONAL QUALIFICATION.

**THE ADDITIONAL QUALIFICATION IS REFERRED TO AS A FITNESS CRITERION**

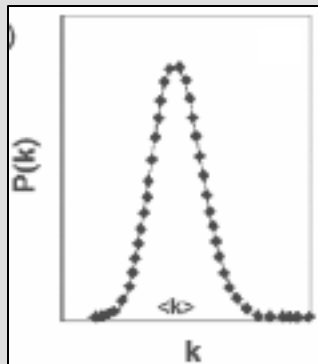
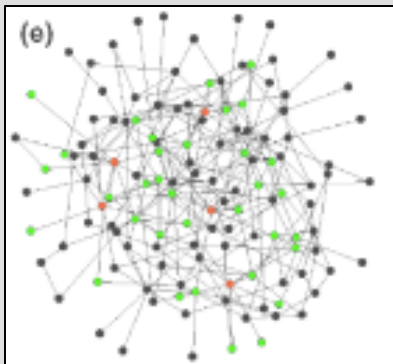
**HUBS REPRESENT THE WELL CONNECTED NODES.**



# DISTINCTION: SCALE-FREE VIS-À-VIS RANDOM NETWORKS



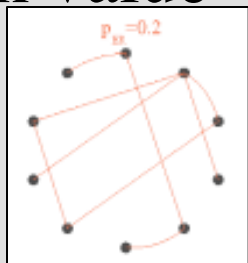
## RANDOM (ERDOS & RENYI, 1950)



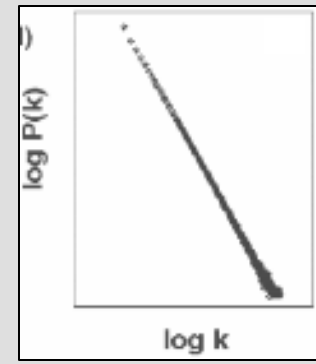
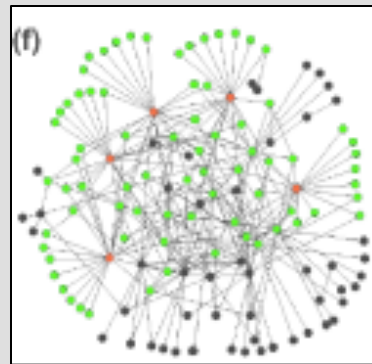
### BINOMIAL( ~POISSON) DEGREE PROBABILITY DISTRIBUTION

$$P(k) = \frac{(np)^k e^{-pn}}{k!} = \frac{\langle k \rangle^k e^{-\langle k \rangle}}{k!}$$

$np$  = mean value



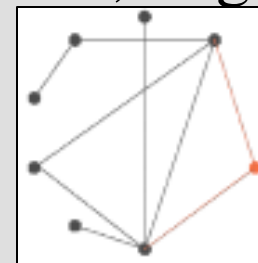
## SCALE-FREE (BARABASI & ALBERT, 2000)



### POWER LAW DEGREE PROBABILITY DISTRIBUTION

$$P(k) = \frac{2m_0^2 t}{(n_0 + t) k^3} \propto k^{-3}$$

$n_0, m_0$  nodes, edges at 0 and  $t$





# WHAT INSPIRES THIS METHODOLOGY?

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**OBSERVATIONS OF EMERGENT SELF-ORGANIZATION OF INTERACTING BIOLOGICAL AGENTS. THE “AGENTS” ARE CAPABLE OF PRODUCING A SYSTEM-WIDE BEHAVIOR USING SIMPLE LOCAL RULES**

**HERE ARE SOME INSPIRING EXAMPLES FROM BIOLOGICAL BEHAVIORAL SCIENCE:**

**FROM SIMPLE RULES TO  EMERGENT SELF-ORGANIZATION**



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# HERDING BEHAVIOR



**NO LEADER! HERDING EMERGES FROM SELF-ORGANIZATION**



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# MIGRATING BIRD FLOCKS



**A MACRO-LEVEL FLOCKING DYNAMIC EMERGES FROM SIMPLE, COORDINATED INDIVIDUAL, MICRO-LEVEL RULES**



## SWARM INTELLIGENCE !



**A COLLECTIVE SYSTEM-LEVEL INTELLIGENCE EMERGES FROM MICRO-LEVEL RULES OF THE CONSTITUENT MEMBERS.**



**AGENTS DO NOT  
SOLVE  
ANY COMPLICATED  
EQUATIONS**



**NOR HAVE FULL  
INFORMATION ON ALL  
AGENTS. THEY DEPEND  
ON LOCAL RULES AND  
INFORMATION.**





# PRACTICAL HUMAN DECISION-MAKING IS SIMILAR IS A SATISFICING SOLUTION



**AS WE UNDERTAKE REALISTIC DECISION-MAKINGS,**

**WE OFTEN DO NOT HAVE ALL THE INFORMATION (AWARENESS) TO BACK OUR DECISIONS. WE DO NOT SOLVE MAJOR EQUATIONS, INTEGRATE VARIABLES ETC TO ARRIVE AT AN OPTIMAL SOLUTION. IN FACT WE NEITHER HAVE THE ABILITY TO INCLUDE ALL RELEVANT FACTORS, THE COMPUTATIONAL ABILITY TO PROCESS THEM, NOR THE TIME TO WAIT LONG-ENOUGH FOR THE OPTIMAL SOLUTION.**

**INSTEAD WE SETTLE FOR A SATISFACTORY AND SUFFICIENT SOLUTION. SUCH A SOLUTION IS A **SATISFICING** SOLUTION.**

**SATISFICING IS FOUNDED ON THE BOUNDED RATIONALITY MODEL OF HUMAN DECISION-MAKING.**

**SATISFICING IS A HALLMARK OF AGENT-BASED MODELING**



## WHO COULD THE AGENTS BE?

No	AGENT	INIT	FUNCTION / EXPLANATION
1	Botswana Power Corporation	BPC	Botswana's only power utility company
2	Energy Affairs Department	EAD	Government Department overseeing energy markets, policy, regulation, guidelines, pricing etc
3	Research Fraternity	RES	General information communication relative to energy research, education, and advocacy
4	Environmental Affairs Department	DEA	Government Department overseeing environmental matters.
5	The Media	MED	Papers, Telephones, Radio, Television, and the New Social Media eg. Mobile phones
6	Ministry of Finance and Economic Development	MFED	Main funder of Government Projects, initiatives, and development projects.
7	Botswana Bureau of Standards	BOBS	Oversees adherence and compliance on locally- and international standards.
8	Public Procurement and Assets Disposal Board	PPADB	Responsible for Government purchases. Can influence import tariffs and custom duties
9	Somarelang Tokologo	SOMT	Botswana Private Environmental "Watchdog", an NGO
10	Southern African Development Corporation	SADC	The Southern Africa Development Corporation. May sway regional energy policy
11	The Botswana Household	HHs	The Botswana Household is the target energy end-user agent in the Agent-based Model.



## EXPECTED ENERGY POLICY IMPLICATIONS



- ◆ **SCALE-FREE NETWORK, WILL ENSURE THAT THE ADOPTION IS ROBUST,**
- ◆ **IDENTIFIABLE HUBS - DRIVERS SUSTAINING THE DIFFUSION PROCESS**
- ◆ **KEY EMERGENT FACTORS - WILL PROVIDE POLICY CLUES, E.G. WHICH POSSIBLE INCENTIVES ARE WORTH TARGETING,**
- ◆ **RESULTS USEFUL TO ENERGY POLICY PLANNERS,**
- ◆ **ACCELERATION OF THE PVT DIFFUSION IN HOUSEHOLDS,**
- ◆ **RESULTS OBTAINED CAN BE CASCADED TO INCLUDE:**
- ◆ **SECTORS OTHER THAN THE HOUSEHOLD SECTOR,**
- ◆ **OTHER NON-SOLAR TECHNOLOGY DIFFUSION,**
- ◆ **OTHER COUNTRIES IN THE REGION, BESIDES BOTSWANA.**



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I THANK  
YOU

