A RAPID SOLAR TRANSITION IS NOT ONLY POSSIBLE, IT IS IMPERATIVE!

[1]David Schwartzman and [2]Peter Schwartzman
[1] Department of Biology, Howard University, Washington, D.C. 20059, USA
dschwartzman@gmail.com
[2] Department of Environmental Studies, Knox College, Galesburg Illinois. 61401, USA

Key words: solar power, catastrophic climate change, energy poverty, fossil fuels

Abstract
Catastrophic climate change (C3) is inevitable if carbon emissions to the atmosphere are not rapidly reduced and the now unsafe atmospheric level (395 ppm) CO_2 (and rising) is not brought down by sequestration technologies to below 350 ppm. C3 prevention is possible with the replacement of global fossils fuel supplies by wind, concentrated solar power and photovoltaics, with the main obstacle being the political economy of global capitalism, specifically the "Military Industrial (Fossil Fuel, Nuclear, State Terror) Complex". There are three critical requirements for the "other world that is possible": demilitarization, agro-ecologies replacing industrial/GMO agriculture, and solarization. Expanding democratic, bottom-up governance is necessary to achieve these objectives. Energy poverty in the global South must end, reaching a rough minimum of 3.5 kilowatt/person. Our simulations show this solar transition is achievable in no more than 30 years with the consumption of less than 40% of the proven reserves of conventional petroleum, while supplying sufficient energy to sequester CO_2 from the atmosphere using a combination of global agroecologies increasing soil carbon storage and solar-powered-industrial-burial of carbonate in the crust. This approach would maximize the possibility of reaching a safe atmospheric CO_2 level before the tipping points to C3 are reached.

Introduction

Humanity is faced with two technological threats to the continuance of human civilization and biodiversity as we know it. The first is the continuing threat of nuclear war, not inevitable but deadly even if localized by virtue of climatic impact on food supplies. The second, catastrophic climate change (C3) is very likely inevitable if carbon emissions to the atmosphere are not rapidly and radically reduced and the now unsafe atmospheric level of 395 ppm CO_2 (and rising) is not reduced by sequestration technologies to below 350 ppm.

An unprecedented path to the "other world that is possible" will be opened up if humanity succeeds in the near future to overcome the obstacles standing in the way of decarbonizing our global energy supplies coupled with rapid implementation of state-of-the-science solar technologies such as wind, concentrated solar power and photovoltaics. The obstacles are not technological, rather lie in the political economy of real existing 21st Century global Capitalism, starting with the Dinosaur sitting in the Room, the Moloch called the Military Industrial (Fossil Fuel, Nuclear, State Terror) Complex. Only a transnational movement for peace and justice can put this Dinosaur in the Museum of Prehistory where it belongs. We argue that there are three critical requirements for that other world that is possible: demilitarization of our global economy, agro-ecologies replacing industrial and GMO agriculture, and the creation of a high-efficiency solar power infrastructure replacing unsustainable fossil fuels and nuclear power. Further, expanding democratic, bottom-up control of the process of transformation of the global economy is necessary to achieve these goals. We may have only 5 years left to begin radical cuts in carbon emissions, according to the most recent assessments, given the continued rise in global carbon emissions [1].

Theoretical Framework

We modeled global solar transition with computed simulations that assumed values for the energy return over energy invested for state of the science of the science wind/solar technologies, "EROEI", i.e., how much energy does the technology such as a photovoltaic array or wind turbine generate in its usable lifetime divided by the energy needed to construct it and maintain it [2]. To our knowledge this was the first study which computed the necessary non-renewable energy (mainly fossil fuel) needed to create the renewable capacity in a solar transition scenario. The critical factor that leads to exponential growth of this renewable energy supply is the feedback of energy from the growing renewable capacity back into the physical economy to create more of itself.

The following equation was used in these simulations

$$d(P_{RE})/dt = [(M/L)(f)(P_{RE})] + [(M/L)(f_{FF})(P_{FF})]$$

RE is defined as the wind/solar technology
P_{FF} : Current power delivery (85% supplied by fossil fuels)
f : fraction of P_{RE} used to make more P_{RE}
f_{FF} : fraction of P_{FF} used to make more P_{RE}
L: lifespan of any RE source
M (= EROI or EROEI): Energy return over energy invested for RE
(M/L) x instantaneous energy invested = instantaneous RE created

Results and Discussion

Some of our results are shown in Figure 1 (go to [2] for more details).

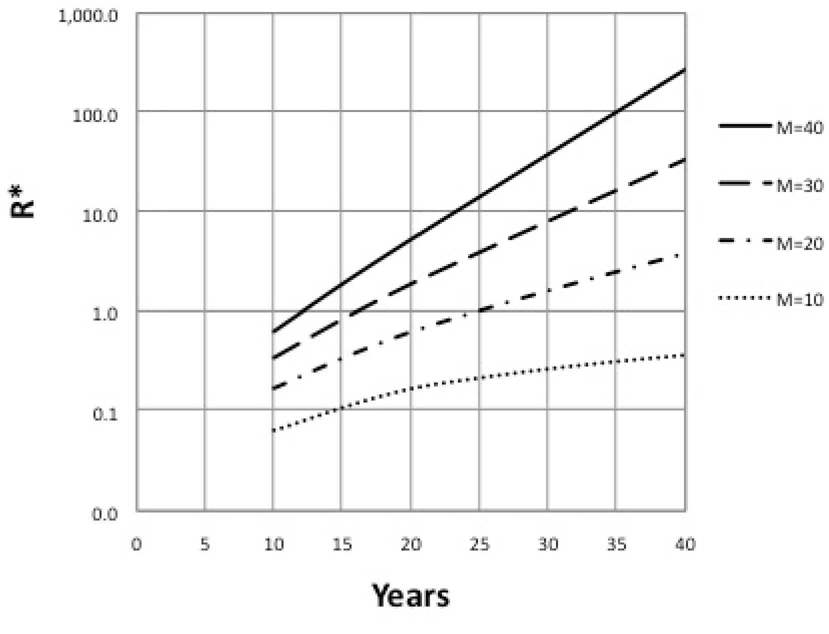

Figure 1. Future Renewable Energy Capacity with different assumed Energy Return Over Energy Invested values ("EROEI") = M for wind/solar technologies. R* is the ratio of future

global renewable power delivery to existing energy generation per year, with 85% presently from fossil fuels. Assumed lifetime of installed wind/solar =20 yrs, with 10% of wind/solar energy produced being reinvested per year in making more of the same, and with 1% of the current annual consumption of energy being used per year to create wind/solar power. State of the science EROEI values of current technologies: Wind turbines: 20 to 75; Photovoltaics: 6 to >10; CSP: 7 to 40. Curves on graph descend from M = 40 (top) to M = 10 (bottom).

Mainly because of its lower carbon emission footprint compared to coal, the preferred fossil fuel to make a solar transition is petroleum (only conventional oil and natural gas, *excluding* the higher carbon footprint tar sands and fracked natural gas, as well as dangerous drilling on deep water continental shelves). We estimate that a robust solar transition can be completed in 20 to 30 years using no more than 40% of the proven conventional reserves of petroleum. The latter requirement will be reduced as higher EROEI wind/solar technologies are developed and put in place in this transition. At the culmination of this solar transition a global increase in energy would be delivered to the world, not a decrease, with many countries in the global North such as the U.S. decreasing their wasteful consumption, while most of humanity, living in the global South receiving a significant increase, reaching the rough minimum of 3.5 kilowatt/person required for state-of-the-science life expectancy levels (see Figure 2). We note that reaching the minimum 3.5 kilowatt/person is necessary but not sufficient for acquiring the highest life expectancy, noting that several petroleum-exporting countries in the Mid-East as well as Russia fall well below this value. Life expectancy for the United States is likewise below most industrial countries of the global North. Income inequality is robustly correlated with bad health and must be reduced to achieve the world

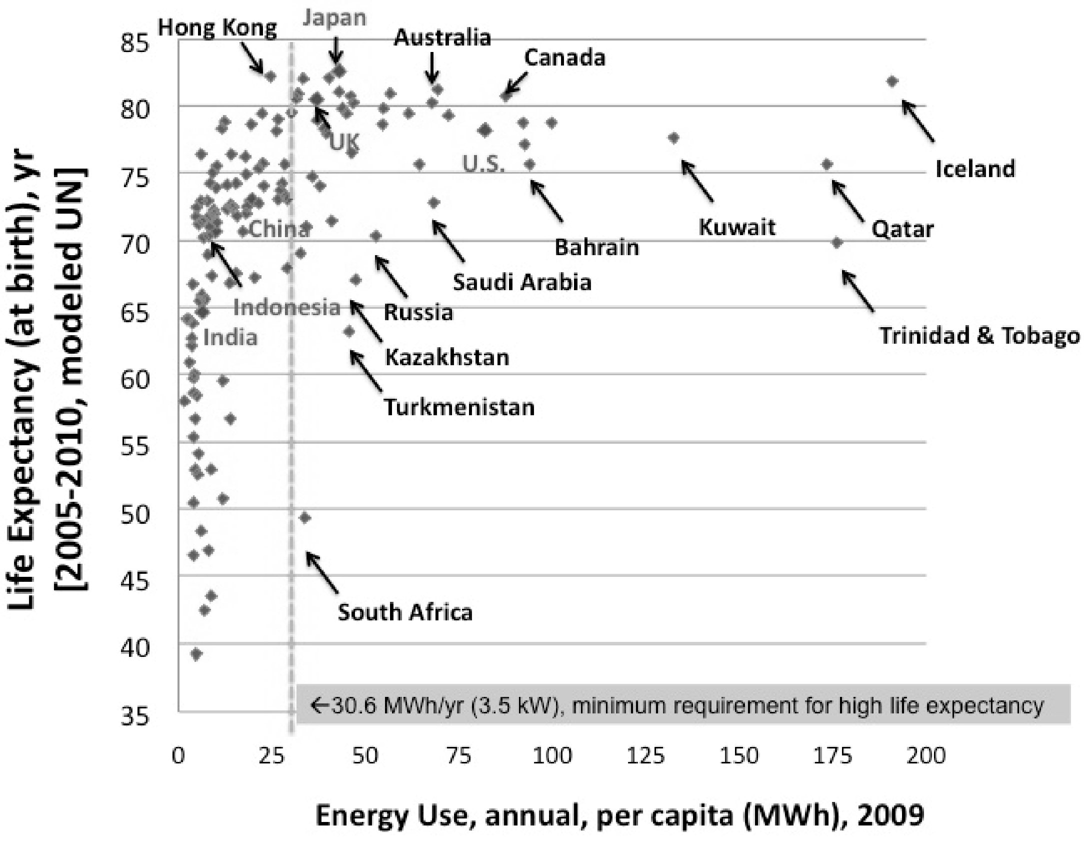

Figure 2. Life expectancy at birth (years) versus Energy use per capita. Source of data: [4].

standard life expectancy and quality of life [3]. Supplying the minimum 3.5 kilowatt/person for the present world population of 7 billion people requires a delivery equivalent to 25 Terawatts (TW), with the present delivery equal to 16 Terawatts (for further details go to www.solarutopia.org). Rapid phase-out of coal use as well as aggressive energy conservation in energy-wasteful countries such as the U.S. is imperative, and must start in the very near future to begin radical reduction in carbon emissions. Further, as the solar transition proceeds, energy conservation in the global North would free up petroleum needed for rapid solar development in the global South. Oil-rich countries in the Mid-East, South America (e.g., Venezuela) and Europe (e.g., Russia) will be valuable partners in this solar transition by providing the needed petroleum. There is little doubt that this transition will require global demilitarization as necessary condition for a global cooperative regime (for documentation go to [15]. If this transition is delayed then humanity will face the virtually inevitable onset of catastrophic climate change. Let's be clear that solar transition must be parasitic on existing energy supplies, just as the industrial fossil fuel revolution was parasitic on biomass energy, so-called plant power, until it replaced the former supply with sufficient capacity. The higher the EROEI value of the wind/solar technology used, the less unsustainable presently-used-energy is needed to effect the solar transition.

A likely maximum of 40% of the proven reserves of conventional petroleum is needed if a robust solar transition starts very soon.

The following provides the basis for our maximum 40% estimate of conventional petroleum needed in our preferred solar transition model to insure a steadily increasing global energy supply to a minimum 3.5 kilowatt/person globally, accompanied by an early phase out of coal, nuclear, big damaging hydropower and most biofuels. Assuming a conservative value of EROEI = 20 for wind/solar, two times the current global energy delivery or roughly 32 TW, corresponding to 9 billion people, is generated for a 20-30 year solar transition with the complete termination of fossil fuel/nuclear/biofuels. In order to ensure a steadily growing global supply of energy, conventional petroleum will provide the complementary supply to the growing wind/solar delivery, with a progressive decrease to zero at the end of the transition. We estimate that no more than 40% of the proven conventional reserves of petroleum (oil and natural gas, excluding tar sands and fracked gas reserves) is needed, roughly 7 ZJ.* The latter requirement will be reduced as higher EROEI wind and solar technologies are developed and put in place in this transition. In addition, coal, nuclear power, as well as hydropower and biofuels with significant carbon footprints, can contribute to RE creation before being phased out completely in the early phase of the transition, and thus this computed fraction of petroleum reserves needed as a backup is a likely maximum. The factors impacting on this estimate are discussed in [2].

* Here is the function used for progressive phase out of non-RE energy sources over the assumed 25 year transition period, with t being the time in years: $FF = 1 - 0.015\,t - 0.001\,t^2$; $\int FF dt$ from t = 0 to 25, gives a total fossil fuel ("FF") consumption equal to 15.1 times the present annual global energy consumption level (0.47 ZJ) or 7.1 ZJ, *which is 43% of the estimated global 16.7 ZJ remaining in conventional petroleum reserves* (oil and natural gas). Note: The "proven" reserves cited do not include tar sands, oil shale or fracked natural gas. In 2008, total worldwide energy consumption was 474 exajoules (474×1018 J=132,000 TWh [5]). Reference [6] cites [7] which estimates remaining natural gas reserves equal to 415 T cubic meters.

If a vigorous solar transition is delayed too long, then and only then will we likely face the gloom and doom scenario of Peak Oil and the virtually inevitable onset of catastrophic climate change, barring the implementation of near future revolutionary solar technologies with much higher EROEI values. Nevertheless, carbon sequestration powered by agroecologies and solar power is imperative, and must start as soon as possible to have any hope of preventing the onset of catastrophic climate change. The longer the excess carbon dioxide remains in the atmosphere the more likely the tipping points for C3 will be reached, therefore radical and early cuts in carbon emissions and carbon sequestration should go hand-in-hand.

Is the baseload supply of energy an obstacle for wind/solar?

Baseload is the backup supply of energy when a particular energy technology is not operating at full capacity. Commonly, supporters of continued reliance on fossil fuels and/or nuclear power raise the objection that wind/solar cannot meet the challenge of baseload. But this claim is misleading. Already available reliable and cheap storage technologies, along with tapping into geothermal energy, will facilitate the expansion of these renewables. However, a big enough array of turbines, especially offshore can likely can generate a baseload without the need to supplement it with separate storage systems [8]. Further, the progressive expansion of a combined system of wind, photovoltaics, and concentrated solar power in deserts will generate a baseload simply because the wind is blowing and the sun is shining somewhere in the system linked to one grid. Meanwhile baseload would be backed up by petroleum, with coal phasing out first, on the way to a completely wind/solar global energy infrastructure.

We have focused on the creation of wind and high efficiency solar technologies in our modeling since these have the greatest potential for not only rapidly replacing the present unsustainable energy supplies but also meeting the energy requirements of all of humanity. Nevertheless, other renewable sources will contribute to the new global infrastructure, notably geothermal (if its hot reservoirs are not depleted), tidal, wind and hydropower (especially small scale). Geothermal power can even become the dominant energy source in some locales (e.g., Iceland and potentially in East Africa). In contrast, most biofuels, such as ethanol derived from corn, are highly problematic, with low EROEI values and undesirable environmental and nutritional impacts.

Carbon-sequestration from the atmosphere must be a component of a solar transition

Carbon sequestration from the atmosphere is imperative, and must start in the near future since the longer the excess carbon dioxide remains in the atmosphere the more likely the tipping points for C3 will be reached. Only the thermal inertia of the oceans responding to the now unsafe and ever rising atmospheric level of CO_2 near 400 ppm gives us a short window of opportunity [9], [10]. Following the analysis provided in [9], a prevention program to have any chance of avoiding catastrophic climate change must include carbon-sequestration from the atmosphere to achieve an atmospheric CO_2 level at or below 350 ppm as soon as possible. A follow up study recommends a 6% cut/year in fossil fuel consumption starting now, with 100 Pg of carbon sequestered from the atmosphere by reforestation from 2031-2080 leaving 350 ppm CO_2 in the atmosphere by 2100 [10]. Lal estimates 2-4 Pg per year of carbon from the atmosphere could be sequestered globally as soil carbon from the atmosphere using agroecological approaches [11]. Assuming a rate of 2 Pg/year, in 50 years 100 Pg of carbon could be sequestered from the atmosphere. A likely complementary approach is solar-powered-industrial carbon sequestration from the atmosphere, burying carbon as carbonate in the crust. Assuming a minimum energy requirement of 442 KJ/mole CO_2 ([12], [13]) 100 Pg of carbon could be sequestered from the atmosphere requiring 3.7 ZJ, equivalent to 7.3 years of the present global energy delivery (16 TW). In a robust solar transition, assuming 7 ZJ of conventional petroleum are consumed in 25 years, with EROEI of wind/solar equal to 25 (same as their lifetime in years) then a total of 51 ZJ is generated, with industrial carbon sequestration energy being 7% of the total. This requirement would of course be reduced by the use of agriculturally-driven carbon sequestration into the soil.

Growth or Degrowth?

The degrowth movement is gaining support in Europe. Richard Heinberg is an influential champion of the Transition City movement. Here is a sample of his argument:

"there is no credible scenario in which alternative energy sources can entirely make up for fossil fuels as the latter deplete. The overwhelming likelihood is that, by 2100, global society will have less energy available for economic purposes, not more…A full replacement of energy currently derived from fossil fuels with energy from alternative sources is probably impossible over the short term; it may be unrealistic to expect it even over longer time frames. . . Fossil fuel supplies will almost surely decline faster than alternatives can be developed to replace them. ..we believe that the world has reached immediate, non-negotiable energy limits to growth." [14]

Au contraire, we show that a complete global transition to wind/solar energy is possible using current technology taking 20-30 years. Richard Heinberg's prescription would doom most of humanity to a future of living hell since *global* energy supplies must be increased to end energy poverty in the global South as well as create the capacity for carbon sequestration from the atmosphere and for the massive cleanup of the biosphere. Nevertheless, while degrowth is a very problematic recipe for global restructuring, it should not be dismissed as a useless response to the unsustainable reproduction of capital, with a reduction in certain kinds of consumption necessary especially in the global North and for elites in the global South. Thus arguments for degrowth should be taken seriously insofar as they address economic activities that increase consumption of fossil fuels, especially coal and tar sands, the two most intense carbon emitters.

The degrowth program is highly problematic because of its failure to analyze the qualitative aspects of economic growth and its emphasis on the local economy without recognizing the urgency to address global anthropogenic change from a transnational political perspective. This demands struggle on all spatial scales, from the neighborhood to the globe.

Global degrowth fails to come to terms with qualitative versus quantitative aspects of economic growth. Further, the energy base of the global physical economy is critical: global wind/solar power will pay its "entropic debt" to space as non-incremental waste heat, unlike its unsustainable alternatives. The concept of economic growth should be deconstructed, particularly with respect to ecological and health impacts. Growth of what are we speaking, weapons of mass destruction, unnecessary commodities, SUVs versus bicycles, culture, information, pollution, pornography, or simply more hot air? Instead, degrowthers commonly lump all growth into a homogenous outcome of the physical and political economy [15].

A Global Green New Deal (GGND) will deliver sustainable growth with huge benefits for both humans and nature, with clean air and water, organic food, meaningful employment and more free creative time for all on this planet [16]. Green sustainable growth will be a transition to a steady-state global solar economy in the 21st Century. Further, the GGND will create the social and material base for bottom-up democratic management of the political and physical economies while still having a chance to prevent C3.

Is the observed and projected market-driven growth of renewable energy capacity, notably of wind and photovoltaics, consistent with our goal? We wrote: "Nevertheless, despite recent developments, the transition to renewables currently underway still lacks the intensity that will allow it to drive the replacement of fossil fuels in a few decades." [2, p. 8]. We stand by this assessment, especially since global fossil fuel use continues to climb at the same time. We estimate that roughly an order of magnitude increase in investment into new wind/solar energy capacity is required. Implementing a GGND would meet this objective.

Conclusion

- A robust solar transition is possible in a few decades, with the potential of avoiding tipping points leading to irreversible catastrophic climate change.

- This transition would simultaneously end energy poverty in the global South, thereby meeting a necessary condition for the state of the science quality of life for all of humanity.

- The biggest obstacle blocking this transition is the Military Industrial (Fossil Fuel, Nuclear, State Terror) Complex. We cannot expect the capitalist market by itself to bypass this obstacle in time to prevent climate catastrophe.

- Only a powerful transnational of peace and justice, organized from the neighborhood to the globe, can overcome this obstacle, insuring this goal is achieved, by forcing rapid reduction in carbon emissions to the atmosphere and the robust creation of wind/solar energy capacity.

- The convergence of the economic, social and ecological/climate crises makes a rapid transition to wind/solar power imperative, hence a Global Green New Deal must be on the agenda for implementation in the very near future.

References

[1] Harvey F (November 9, 2011) World headed for irreversible climate change in five years, IEA warns If fossil fuel infrastructure is not rapidly changed, the world will 'lose for ever' the chance to avoid dangerous climate change. http://www.guardian.co.uk/environment/2011/nov/09/fossil-fuel-infrastructure-climate-change.

[2] Schwartzman P & Schwartzman D (2011) *A Solar Transition is Possible.* http://iprd.org.uk and http://www.solarutopia.org.

[3] Wilkinson R & Pickett K (2009) *The Spirit Level Why Equality is Better for Everyone*. Penguin Books. London. Kawachi I & Kennedy BP (2006) *The Health of Nations: Why Inequality Is Harmful to Your Health.* The New Press. New York.

[4] http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE, http://en.wikipedia.org/wiki/List_of_countries_by_life_expectancy.

[5] http://en.wikipedia.org/wiki/World_energy_consumption.

[6] Smil V (2008) *Energy in Nature and Society.* MIT Press. Cambridge.

[7] Ahlbrandt TS, Charpentier RR, Klett TR, Schmoker JW, Schenk CJ, & Ulmishek GF (2005) *Global Resource Estimates from Total Petroleum Systems*. Tulsa, Okla. AAPG.

[8] Archer CL & Jacobson MZ (2007) Supplying baseload power and reducing transmission requirements by interconnecting wind farms, *J. Applied Meteorol. and Climatology* **46**, 1701-1717, www.stanford.edu/group/efmh/winds/. Kempton W, Pimenta FM, Veron DE & Colle BA (2010) Electric power from offshore wind via synoptic-scale interconnection. *PNAS* **107**: 7240-7245.

[9] Hansen J, Sato M, Kharecha P, Beerling D, Berner R, Masson-Delmotte V, Pagani M, Raymo M, Royer DL & Zachos JC (2008) Target atmospheric CO_2: where should humanity aim? *Open Atmos. Sci. J.*, **2**, 217-231.

[10] Hansen J, Kharecha P, Sato M, Epstein P, Hearty PJ, Hoegh-Guldberg O, Parmesan C, Rahmstorf S, Rockstrom J, Rohling EJ, Sachs J, Smith P, Steffen K, von Schuckmann K & Zachos JC (2011) The Case for Young People and Nature: A Path to a Healthy, Natural, Prosperous Future. http://www.columbia.edu/~jeh1/mailings/.

[11] Lal R (2010) Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security. *BioScience* **60**, 708-721.

[12] House KZ, Baclig AC, Ranjan M, van Nierop EA, Wilcox J & Herzog HJ (2011) Economic and energetic analysis of capturing CO_2 from ambient air. *PNAS* **108**, No. 51: 20428-20433.

[13] Zeman F (2007) Energy and material balance of CO_2 capture from ambient air. *Environ. Sci. Technol.* **41**, 7558-7563.

[14] Quotation posted from Heinberg R (2009) *Searching for a Miracle: Net Energy Limits and the Fate of Industrial Societies.* International Forum on Globalization and Post Carbon Institute. http://www.postcarbon.org/article/254838-earth-s-limits-why-growth-won-t-return. Also see: Heinberg R (2011) *The End of Growth.* New Society Publishers. British Columbia, Canada.

[15] Schwartzman D (2012) A Critique of Degrowth and its Politics. *Capitalism Nature Socialism* **23**, (1) 119-125. Schwartzman D (2009) Ecosocialism or Ecocatastrophe? *Capitalism Nature Socialism* **20**, (1) 6-33.

[16] Schwartzman D (2011) Green New Deal: An Ecosocialist Perspective. *Capitalism Nature Socialism* **22**, (3) 49-56.

TOWARDS A TECHNOLOGY POLICY FOR RENEWABLE ENERGY DEVELOPMENT IN AFRICA: AN INNOVATION SYSTEMS PERSPECTIVE

Ogundiran Soumonni
School of Public Policy, Georgia Institute of Technology
685 Cherry Street, Atlanta, Georgia 30332-0345, U.S.A.
Fax : (1)404-385-0504 ; E-mail: diran.soumonni@gatech.edu

Keywords: Learning, Innovation Systems, Technology Policy, Innovation Policy, Renewable Energy, Electricity, Energy Policy

Abstract:
Several important thinkers have argued, historically, that the industrialization of Africa is the key to its long term economic well-being. Nevertheless, very few of its countries have seriously attempted it in the post-independence era, instead adopting development schemes that overlook or bypass this critical factor. The objective of this paper is to use the innovation systems perspective (IS) to describe how African countries might increase their rates of access to electricity, and by extension, their capacity for broad-based industrialization, through renewable energy. This approach goes beyond a narrow focus on R&D and markets, to include the larger set of political, institutional, economic and cultural factors that are vital to the innovation process. The first part of the paper explains the concept of "learning" which is central to the IS perspective, and is a major driver of innovation and production. Secondly, the paper provides some examples of attempts to develop renewable energy industries around the continent, and thirdly, it explains how the research outputs of networks such as the African Network for Solar Energy (ANSOLE) can be transformed into inventions, and describes the more crucial process of how some of those inventions might be converted into innovations. The main policy recommendation is that there should be a division of "innovative labor" in Africa, whereby a technological leader like South Africa, which invests in R&D, for instance, can network more closely with other African countries involved in manufacturing or assembly, while establishing preferential licensing and patenting agreements with them. Combined with community-based innovation strategies, this could serve to more effectively transfer "sticky" or tacit knowledge, by connecting the innovation of the producers with that of the users in a manner that is consistent with the tenets of appropriate technology.

INTRODUCTION

The view that the industrial development of Africa is critical to the emancipation of its peoples both on the continent and in its diaspora was shared by virtually all the most important thinkers of African descent who contributed to its liberation from colonial rule. While the antecedents of this thinking can be traced to the 19th century, some of the better known proponents of this view in the 20th century include Marcus Garvey, Cheikh Anta Diop, Kwame Nkrumah, Julius Nyerere and Walter Rodney. Earlier in that century, for instance, Marcus Garvey famously contended that "power" was the only argument that could satisfy people, and therefore, he advocated for the building of an industrial superpower on the continent that would be respected by other nations and could ultimately protect Africans around the world. The late Professor Cheikh Anta Diop would later provide one of the most cogent and comprehensive analyses on the subject, when he presented a compendium of the energy resources available in Africa, which combined with his identification of the raw materials that exist in different areas, could establish the basis for eight natural zones for its industrial development [1].

For various reasons that go beyond the scope of this paper, the emphasis on industrialization as the basis for autonomous development in the modern world has all but disappeared from the official discourse in most African countries. In sub-Saharan Africa, for instance, South Africa is the only semi-industrialized country, but it is characterized by a bi-furcated economy, with both technologically advanced areas and largely non-industrialized regions. Following the end of apartheid rule in 1994, the newly democratic South Africa was the first African country to adopt the National Innovation Systems (NIS) approach, and formally made it a government policy in 1996 [2]. Its current Ten-Year Innovation Plan, initiated in 2008, also uses the NIS language, and has the goal of moving the country from a resource-based economy to a knowledge-based one in order to address its "grand challenges", which include biotechnology, space technology, climate change, energy security, and human and social dynamics.

The first part of the paper explores the notion of learning in the IS framework, which explains the process of accumulation of skills and knowledge, with an emphasis on the interaction between the actors and organizations in a given system that lead to an increase in technological productivity. This section also provides an overview of the innovation systems perspective, and highlights some conditions under which it is relevant to non-industrialized regions in general. The second part of the paper gives a few experiences of trying to establish a renewable energy industry in various parts of the continent, while the third part of the paper employs ideas from innovation theory to explain how the outputs of African renewable energy researchers can ultimately become technological innovations. The third section also describes some patenting strategies that can be adopted by small firms, in particular, in order to protect their creativity, promote their innovative potential, and increase their overall societal impact. Finally, some conclusions and policy recommendations are provided as to some of the ways to better promote a renewable energy industry in Africa.

"Learning" and the Innovation Systems Perspective:

The concept of learning is central to Innovation Systems thinking, and can be understood as a process of technical change that is achieved by diffusion, the adoption of innovations produced elsewhere, and incremental innovation of acquired techniques[3]. Four types of learning can be identified as being crucial to the innovation process, namely, learning by searching, learning by doing, learning by using, and learning by interacting [4]. Learning by searching refers to the systematic search for new knowledge and is synonymous with research and development (R&D), learning by doing denotes the practical experience or the know-how needed to manufacture a product, learning by using is the knowledge that is acquired by adopting and using a particular product, while learning by interacting occurs through persistent user-producer relations and is required for a successful innovation [4].

In the context of non-industrialized or late industrializing economies, most of the learning that is tacit and localized knowledge, occurs through the DUI (Doing, Using and Interacting) mode, thereby connecting the innovation of the user and that of the producer through the flow of goods and services [5]. However, because innovation, strictly speaking, is more like creation than learning alone, Viotti (2002) suggests that the term 'National Learning Systems' should be used in place of 'National Innovation Systems' for those late industrializing economies that are characterized by technological learning rather than innovation per se [3]. For these countries, he distinguishes between a passive learning strategy in which the technological effort is mainly targeted at the simple assimilation and absorption of production capability, while an active learning strategy goes beyond the mere absorption of production capability and aims at the mastery of both production and improvement capability [3]. This paper argues, nonetheless, that African countries can and should aspire to proceed to the full-fledged innovation stage, particularly with respect to renewable energy.

Since its introduction, the Innovation Systems framework has taken two main perspectives. The first is a narrow perspective, which focuses on mapping indicators of national specialization and performance regarding innovation and R&D efforts, while the second is broader, and includes wider considerations such as education, social institutions, macroeconomic conditions, and communication infrastructure, particularly with respect to their impact on the process of learning and competence building [5]. In the majority of sub-Saharan African countries, for example, there is a widespread assumption of straightforward links between basic knowledge generation from educational and R&D institutes to the economic agents that apply this knowledge [6]. This conjecture helps to explain the poor state of industry in the region given the strong evidence of de-industrialization from strong positive growth in the 1960s to weak or negative growth in the 1980s, and a slight increase in the 1990s [6].

"Learning" and Innovation in Renewable Energy

Without losing sight of some of the different ways in which knowledge and innovation function in the global North and South as explained in the previous section, an examination of a few international experiences can help to demonstrate the relevance and applicability of the concepts of learning and innovation to the field of renewable energy. The Dutch experience with wind turbine development, for instance, reveals that its dominant mode of learning was through learning by searching, that is, the traditional "science-push" innovation system predominantly based on subsidies for R&D [4]. In Denmark, on the other hand, learning by using and learning by interacting between the producers of turbines, users of turbines and the Danish Research Institute were privileged through investment subsidies for turbine manufacturers [4]. As a result, even though both countries started developing wind energy in the 1970s, by the year 2000, the Netherlands had only one turbine manufacturer left out of ten to fifteen originally, with a total installed capacity of 442 MW (the target was 2000 MW), while Denmark had a cumulative installed capacity of 2340 MW with a thriving industry that produced wind turbines for the global market [4].

China's approach to developing its rural electrification program corresponds to the learning by doing, using and interacting (DUI) mode of innovation. In the case of its small hydroelectric projects (SHPs), it used a step-by-step strategy that was guided by three principles, namely: 1.) self-construction (learning by doing), whereby local governments and people were encouraged to use local materials, technology and water resources to build the systems; 2.) self-use (learning by using), which required the electricity produced by the stations to be used locally while not allowing the conventional grid to compete in locally integrated markets; and 3.) self-management (learning by interaction), which allowed investors to own and manage the stations, thereby avoiding administrative interference and preserving the enthusiasm of the local communities to develop SHP [7].

In 2010, China became the largest supplier of wind turbines in the world, accounting for over 50 percent of new wind turbines, and adding nearly 19 GW of capacity in that year [8]. One of the explanations for this rapid growth is that its wind industry emerged from other segments of its diverse industrial base that already had a high-level manufacturing capability. China also strategically used its licensing agreements with European companies by focusing on joint design and collaboration rather than Foreign Direct Investment (FDI) and trade, for its own learning and innovation [8]. Furthermore, its dominant wind turbine producers, which are subsidiaries of state-controlled power generation firms, built up substantial in-house R&D capability, while benefitting from lower feed-in tariffs for local service provision than foreign firms [8].

Innovation in the Renewable Energy Industry in Africa: An Overview

The role that renewable energy has the potential to play in Africa's economic and industrial development cannot be overstated. According to a 2009 UNDP survey, only about a quarter of the population in Sub-Saharan Africa had access to electricity and ten countries recorded a national access rate of less than 10%. In rural areas, where approximately 80% of the population lives, the access rate is typically less than 3%, with a few exceptions such as Zimbabwe with an electrification rate of 18% for its rural population [9]. South Africa's electrification program, though primarily based on coal, has shown the most outstanding results, going from a rate of access of less than a third in 1990 to over 80% in 2009, including an estimated number of more than five million newly connected households [10]. Although it is not yet widespread in West Africa, I have discussed elsewhere in detail, the potential for distributed generation (DG) of renewable energy as a bottom-up approach to meet the needs of people who are not currently connected to the grid [11], as well as some alternative financing mechanisms that could promote domestic ownership of the electricity sector through DG [12].

Studies on the adoption of PV systems in Africa suggest that their adoption is greater in Southern and Eastern Africa, than in West and Central Africa [13, 14]. In the year 2000, Kenya and South Africa had about 150,000 Solar Home Systems (SHSs) each, followed by Zimbabwe with 85,000, and Uganda and Tanzania rounded out the top five with 20,000 and 10,000 SHSs respectively [14]. While worldwide PV prices have been reduced as a result of advances in innovation in manufacturing and economies of scale in production, the prices remain much higher in Africa than in other parts of the world, in part because of the taxes and high transaction costs incurred in supplying the systems. One exception is Kenya, where reductions in the import tariffs as well as intense competition have lowered the prices [14]. More importantly, however, the prices would be even lower if the systems were produced domestically.

A review of the solar photovoltaics (PV) industry in Africa has highlighted three issues that are critical to its future development, namely: 1.) technology development, which is characterized by both community-level uses such as water pumping or household electricity, and larger scale needs such as agro-industry and public health; 2.) education; and 3.) finance [13]. These can also be extended to other renewable energy industries, and the regional experiences described below underscore these concerns.

[1] *The Southern African Industry:*

Whereas most of the global production of solar cells and wafers is located in the industrialized countries, there have been very few attempts at manufacturing solar panels in Africa, mainly in Zimbabwe and South Africa. According to one account, a solar equipment and manufacturing company known as Solarcomm with a workforce of fifty people, commissioned a new plant in Zimbabwe in 1987 to produce state of the art equipment of the same quality as any imported product [15]. About four years later, a Danish organization called the Danish Federation of Small and Medium-sized Enterprises (DFSME) approached Solarcomm to develop mutually beneficial commercial opportunities. After efforts to adapt Danish designs to the Zimbabwean manufacturing capabilities, the final product was deemed ready for full scale production in 1993, but this production did not take place due to disagreements at the managerial level, which resulted in the DFSME partnering with the major competitor to Solarcomm, a company called Solamatics (PVT) Ltd. The new partnership then successfully produced photovoltaic vaccine refrigerators, solar-powered navigational equipment, and solar water heaters for export to other countries of the Southern African Development Community (SADC) [15]. Some of the key lessons from this technology transfer experience were that there must be local know-how at the factory level and opportunities for additional training, the existing management should be able to further

develop a technology without external assistance once it has been transferred, and there should be capable infrastructure, including a consistent supply of electricity [15].
In 2005, Prof. Vivian Alberts of the University of Johannesburg developed a low-cost thin film solar photovoltaic technology based on Copper Indium Gallium diSelenide, but later licensed it to the German manufacturer, Aleo Solar [16]. One observer of the South African energy industry has attributed the inability for this invention to be produced domestically to an inadequate institutional and legal framework, insufficient financing, and a lack of specialized solar PV manufacturing capability [17]. Two of the main manufacturers of PVs in South Africa, Solaire Direct and Tenesol, are both subsidiaries of French-owned companies [18]. However, the first wind turbine rotor blade manufacturing plant in South Africa was launched in November, 2011, by a Cape Town-based company by the name of Isivunguvungu, which means "big wind" in both *isi*Xhosa and *isi*Zulu [19].

[2] *The West African Industry:*

The establishment of the first solar panel production line in West Africa was announced in January 2011 by the Sustainable Power Electric Company (SPEC) of Senegal, which bought a 15 MW solar production line from the Swiss company 3S Modultec together with a comprehensive training package, a service and maintenance contract, and the certification of the panels to be manufactured [20]. SPEC, which already has a technology and innovation center that specializes in solar energy for the development of major projects, plans to expand the production line to 25 MW. It also expects to have the ability to combine automated and semi-automatic production stages, with experts from 3S Modultec assisting the local SPEC team to monitor the project throughout the planning, ramp-up, launch and certification stages [20].
Later in the same year, in November 2011, the Nigerian National Agency for Science and Engineering Infrastructure (NASENI) established a partnership with an unnamed foreign firm to establish a 7.5 MW solar module factory that would produce PV panels for small-scale off-grid applications throughout Nigeria[21]. It ultimately plans to build a solar cell factory that can produce solar panels using locally grown silicon ingots [21]. However, the present author is not able confirm whether production has actually begun in either Nigeria or Senegal.

Bridging the Gap between Research and Innovation:

The African Network for Solar Energy (ANSOLE) is a network that was founded in 2010 to foster education and training at different skill levels, promote research activities among African scientists working both on the continent and in its diaspora, and to encourage the use of solar energy in Africa, including through the use of African languages. Many researchers in the network, which now consists of about 200 members, do not think that Africa can compete in the already advanced field of silicon-based PV, but organic polymer-based solar cells are attracting their attention because of their relative ease of processing, their flexibility, and their low cost - advantages that compensate for their currently low efficiency [16].
Even though the type of interactions between researchers fostered by ANSOLE will help lead to inventions that can be protected by patents, the ability to transform these inventions into innovations that produce regular benefits for the firm and for the users is not a trivial task. The process involves creating a social system that has to nurture technical ideas, make investments in risky situations, and arrange the division of benefits so that both investors and personnel are motivated to develop the competences that are needed to do all these things, and actually do them [22]. Where this environment does not yet exist and international joint ventures are needed, this should be done in a way that makes it possible to develop the necessary capability in the host country. It should also be noted that multinationals do not particularly like international joint ventures and that typically, ventures between the firms of

friendly nations are much more productive than those with less friendly nations, or those with which they have weak network ties [23]. Similarly, Foreign Direct Investment (FDI) is much more likely to produce knowledge spill-overs between countries that have a similar level of economic development than between industrialized and less industrialized ones.

Historically, trial and error had been the main engine of innovation, but with advances in both theoretical knowledge and the tools for laboratory research, a greater number of firms have the opportunity to introduce more innovations. However, because the technical information required to solve a problem is expensive to acquire, transfer and then use in a new place, the abstract knowledge shared by networks must be brought together with the problem-solving capabilities of emerging firms in order to find an innovative solution. This is what is known as "sticky information" [24]. In addition, the literature on patenting strategies suggests that other means of appropriating rents such as secrecy or first mover advantage are more important than patents in most industries, and that broader patents would increase the rate of technological progress by promoting small firms or innovators that lack size and downstream capabilities [25].

Conclusions:

The demand for renewable energy in Africa is very large due to the low rates of access to modern energy, and electricity more specifically. This situation provides a natural incentive for Africa to develop a renewable energy industry that can provide affordable solutions to meet this demand. The concepts of learning and innovation systems were presented in this paper as theoretical notions that can help to guide the process of industrialization in Africa in general, and in the field of renewable energy more specifically. Despite the fact that there are a number of countries where the adoption of renewable energy is growing, mainly in solar PV applications, there are hardly any indigenous industries currently producing these technologies.

The paper recommends that the research outputs of networks of scientists such as ANSOLE be further interconnected with the users and producers of renewable energy technologies in order to convert their knowledge into inventions, and more importantly, turn those inventions into usable products. This process requires a coherent technology policy that includes astute patenting strategies, judicious licensing agreements, and a division of innovative labor, whereby a country like South Africa, with its large research base could employ an "active" learning strategy to collaborate closely with Zimbabwean firms that have experience with manufacturing to bring their research to fruition. Similarly, West African or East African firms could obtain preferential licensing agreements with Southern African firms to bolster their manufacturing capabilities through "passive" learning in the initial stages. In addition, universities and technical schools, and even secondary educational institutions, can train more young people to develop and manage distributed renewable energy systems in their communities. Such initiatives would serve to enhance technological learning and competence building, as well as improve Africa's ability to innovate in a manner that is consistent with the key characteristics of an appropriate technology, namely, sustainability, ownership, and suitability as an intermediate technology.

REFERENCES

1. Diop, C.A., *Black Africa - The Economic and Cultural Basis for a Federated State*1987: Lawrence Hill Books.

2. Maharajh, R., *Innovating beyond Racial Capitalism: A Contribution towards the Analysis of the Political Economy of Post-apartheid South Africa*, in *Research Policy Institute*2011, Lunds University: Lund, Sweden. p. 294.

3. Viotti, E.B., *National Learning Systems: A New Approach to Technical Change in Late Industrializng Economies and Evidence from the Cases of Brazil and South Korea.* Technological Forecasting and Social Change, 2002. **69**(7).

4. Kamp, L.M., R.E.H.M. Smits, and C.D. Andriesse, *Notions on learning applied to wind turbine development in the Netherlands and Denmark.* Energy Policy, 2004. **32**: p. 1625-1637.

5. Lundvall, B.-Å., et al., *Innovation system research and developing countries*, in *Handbook on Innovation Systems and Developing Countries: Building Domestic Capabilities in a Global Setting*, B.-Å. Lundvall, et al., Editors. 2009.

6. Adeoti, J.O., *Building technological capability in the less developed countries: the role of a national system of innovation.* Science and Public Policy, 2002. **29**(2): p. 95-104.

7. Yao, X. and D.F. Barnes, *National Support for Decentralized Electricity Growth in Rural China*, in *The Challenge of Rural Electrification: Strategies for Developing Countries*, D.F. Barnes, Editor 2007, RFF Press: Washington, DC. p. 225 - 258.

8. Lema, R., et al., *Competition and Cooperation between Europe and China in the Wind Power Sector.* IDS Working Paper, 2011. **2011**(377).

9. Karekezi, S. and W. Kithyoma, *Renewable energy strategies for rural Africa: is a PV-led renewable energy strategy the right approach for providing modern energy to the rural poor of sub-Saharan Africa?* Energy Policy, 2002. **30**: p. 1071-1086.

10. Bekker, B., et al., *South Africa's rapid electrification programme: Policy, institutional, planning, financing and technical innovations.* Energy Policy, 2008. **36**: p. 3115-3127.

11. Soumonni, O. *A Bottom-up Approach to Energy Policy Planning in West Africa: The Case of Distributed Generation of Renewable Electricity*. in *Proceedings of the 4th International Conference on Appropriate Technology.* 2010. Accra, Ghana.

12. Soumonni, O.C. and O.Y. Soumonni, *Promoting West African Ownership of the Power Sector: Alternative Financing for Distributed Generation of Renewable Electricity.* Journal of African Business, 2011. **12**(3): p. 310-329.

13. Cope, G., F. Aghdasi, and M.D. Dlamini, *A Review of the Photovoltaic Industry and its Development in Africa.* Solar Energy, 1997. **59**(4-6): p. 217-225.

14. Moner-Girona, M., et al., *Decreasing PV Costs in Africa.* Refocus, 2006. **7**(1): p. 40-45.

15. Mollat, M. *The Denmark-Zimbabwe Technology Partnership Projects in Solar Equipment Manufacturing*. UNCTAD Technology for Development Series, 2009.

16. Ottery, C. *The solar researchers aiming to light up Africa*. The Science and Development Network 2012; Available from: http://www.scidev.net.

17. Perrot, R., *SA's low-carbon entrepreneurs need much greater support*, in *Business Day*2012, BDFM Publishers (Pty) Ltd.: Johannesburg, South Africa.

18. Hirshman, W.P. *Home sweet home for PV?* PHOTON International: The Solar Power Magazine 2011; Available from: https://photon-international.com.

19. Bretenbach, K., *Isivunguvundu Wind Energy Converter launches South Africa's first wind turbine rotor blade manufacturing plant.* Energy Management News, 2011. **17**(4): p. 1-2.

20. Knaus, A. *3S Modultec Sells Integrated Solar Panel Production Line to West Africa*. 2011; Available from: http://www.meyerburger.com.

21. Beebe, D. *Nigerian Solar Module Factory Targets Off-grid Installations*. PHOTON International: The Solar Power Magazine 2011; Available from: www.photon-international.com.

22. Stinchcombe, A.L., *Turning Inventions into Innovations*, in *Information and Organizations*1990.

23. Powell, W.W., *Neither Market Nor Hierarchy: Network Forms of Organization.* Research in Organizational Behavior, 1990. **12**: p. 295-336.

24. Hippel, E.V., *Sticky Information and the Locus of Problem Solving: Implications for Innovation.* Management Science, 1994. **40**(4): p. 429-439.

25. Arora, A. and A. Gambardella, *The changing technology of technological change: General and abstract knowledge and the division of innovative labor* Research Policy, 1994. **23**: p. 523-532.

FREQUENCY SENSING OF AN ISOLATED PICO-HYDRO POWER GENERATION PLANT USING MAGNETOSTRICTIVE AMORPHOUS WIRE

[1]Nderu J. N, [2]Kitur C. K., [3]Kaberere K., and [4]Muhia A. M.,
[1]Jomo Kenyatta University of Agriculture and Technology, P. O. Box 62,000, Nairobi
[2]Kimathi University College of Technology, P. O. Box 657, Nyeri
[3] Jomo Kenyatta University of Agriculture and Technology, P. O. Box 62,000, Nairobi
[4] Kimathi University College of Technology, P. O. Box 657, Nyeri
Email: ckitur@gmail.com

Keywords: Frequency, Isolated Pico-hydro, Large Barkhausen jump, Magnetostrictive amorphous wire, Synchronous generator**.**

Abstract

This paper presents frequency measurement of uncontrolled turbine isolated pico-hydro power generating plant using magnetostrictive amorphous wire (MAW). The basic principle of the measurement is based on large Barkhausen jump (LBJ), sudden reversal of magnetization when the magnetic field reverses resulting in voltage spikes being induced in a pick-up coil wound around the MAW to pick the spikes. The number of spikes recorded per second is actually the frequency of generation. This is compared with the measured frequency of the generated power as read from the generation meters and also as calculated based on measured speed of rotation and results are presented.

INTRODUCTION

Isolated Synchronous Generator

Synchronous generators are by definition synchronous, meaning that the electrical frequency produced is locked in or synchronized with mechanical rate of rotation with the generator [1]. Most synchronous generators are constructed such that they have a rotating magnetic field. The rotor field faces whatever direction the rotor is turned as they excite the stator windings, which results in terminal voltage being generated as given by the equation

$$E_A = K\emptyset\omega \tag{1}$$

Where

- E_A Generated voltage
- K Machine constant
- $\emptyset$ Magnetic flux of the machine
- ω Speed of rotation in mechanical radians

The frequency of generation of this voltage is also dependent on the speed of rotation of the rotor (mechanical speed of the magnetic field) and the number of poles of the machine as given by the following equation

$$\mathbf{f_e = \frac{n_m P}{120}} \tag{2}$$

Where

- f_e Electrical frequency in Hertz (Hz)
- n_m Mechanical speed of the magnetic field
- P Number of poles

Most generators are interconnected onto an infinite bus bar system. In interconnected system, synchronous generators not only rotate at exactly the same frequency, but are also in step with each other, meaning that the timing of the alternating voltage produced by each generator coincides very closely. This is a physical necessity if all generators are simultaneously to supply power to the system [2]. However, for an isolated generating plant, change in speed of rotation causes change in frequency and voltage as can be seen from preceding equations. Voltage is easily controlled by automatic voltage controllers, whereas for frequency, controlled turbines are used. This work presents the use of MAW to sense frequency of generated power for possible use in control of pico-hydro power generation plant.

Magnetostrictive Amorphous Wire

Magnetostrictive amorphous wire is prepared by rapid quenching in rotating water. The molten alloy cools rapidly to bypass crystallization phase resulting in a wire shaped amorphous solid [3]. This MAW has unique properties and has found applications in various electronic sensors and devices [4]. In this work, Large Barkhausen jump (LBJ) is employed. The amorphous sensor wire used in this system is of composition $(Fe_{50}Co_{50})_{78}Si_9B_{13}$, 7cm in length (which is a critical length needed to sustain (LBJ) and 125μm diameter [5]

EXPERIMENTAL PROCEDURE

This experiment is set up as shown in the figure 1. DC series motor is used as a prime mover because of its torque speed characteristic, which shows that with a constant voltage source, speed reduces with increase in loading, as the motor is loaded, the torque developed by it must increase. The increase in the torque necessitates an increase in the armature current. The increase in the armature current causes an increase in the voltage drop across the armature-circuit resistance, the field-winding resistance, and the external resistance. For a fixed applied voltage, the back emf must decrease with load. Since the back emf is also proportional to the armature current, the speed of the motor must drop [6]. In a typical pico-hydro generating plant, the prime mover is relatively constant but as load increases, the speed of the generator reduces as it is loaded. This is also a case with DC series motor. The voltage supply of a DC series motor is adjusted to its rated value; this drives the motor to a speed slightly above 3,000 rpm. This motor is used to drive a three phase generator which is connected to supply a balanced three phase resistive load. The generator is then loaded with various loads from no load to the maximum available load as tabulated in table 1.

Small permanent magnets are attached to the generator shaft. As the generator rotates, the permanent magnet attached to it also rotates at the speed of the rotor. Voltage is induced in the MAW each time the pole passes near it; these are fed into a digital oscilloscope for display and to read the signal properties as picked by the MAW. This includes frequency and peak to peak voltage. Tacho generator is also attached to the motor shaft for speed measurements from which, the frequency can be calculated using equation 2, and the results are presented as tabulated in table 1. Direct measurement of the frequency is also made using generation meters, this is where the generated power is passed through the energy meter which measures; voltage, frequency, currents, active power, reactive power, and harmonic distortions and the results are presented.

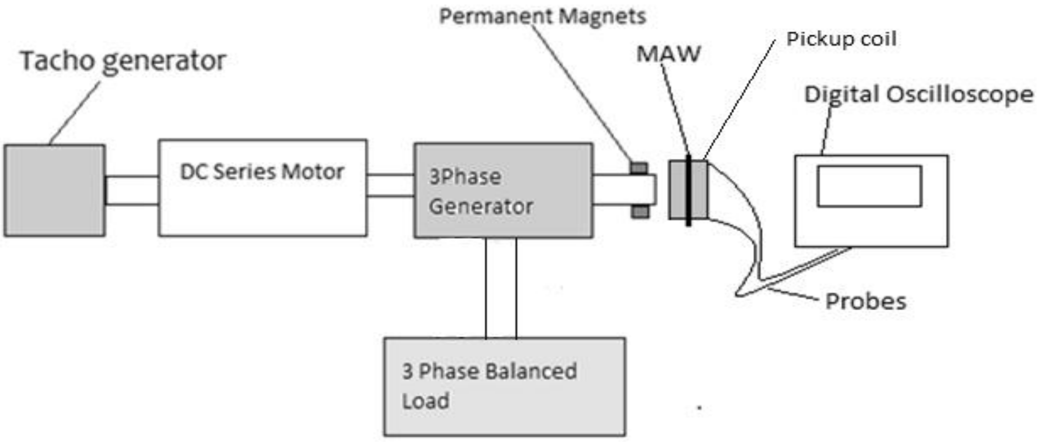

Figure 1: Experimental set up (Not drawn to scale)

RESULTS AND DISCUSSION

The following are the results of the experiment using MAW and digital oscilloscope to read the frequency.

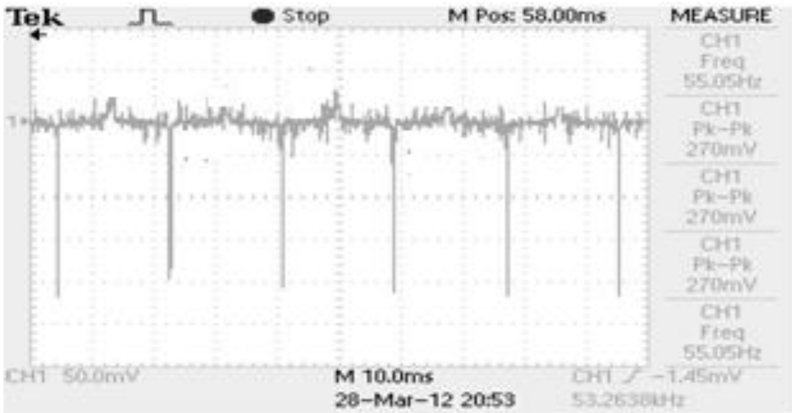

Figure 2 : No load

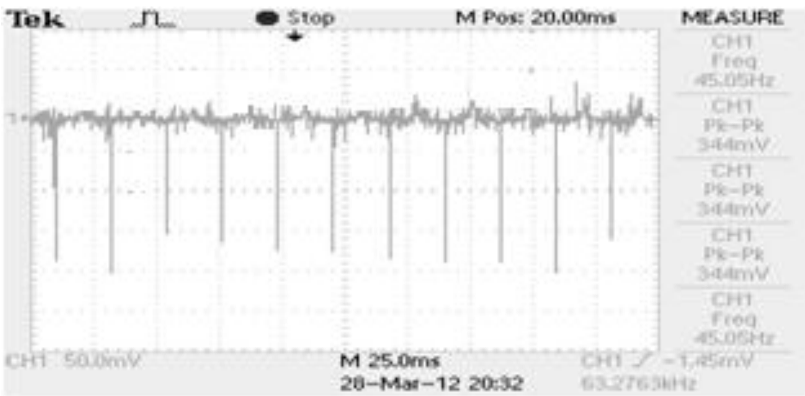

Figure 3: Generator supplying a load of 82.1W

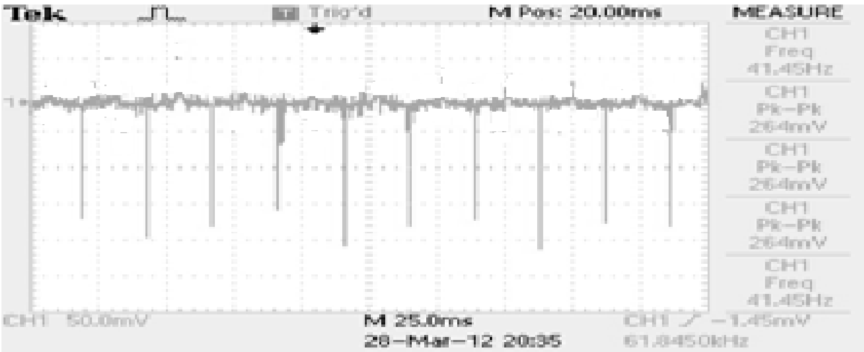

Figure 4: Generator supplying loa d of 135W

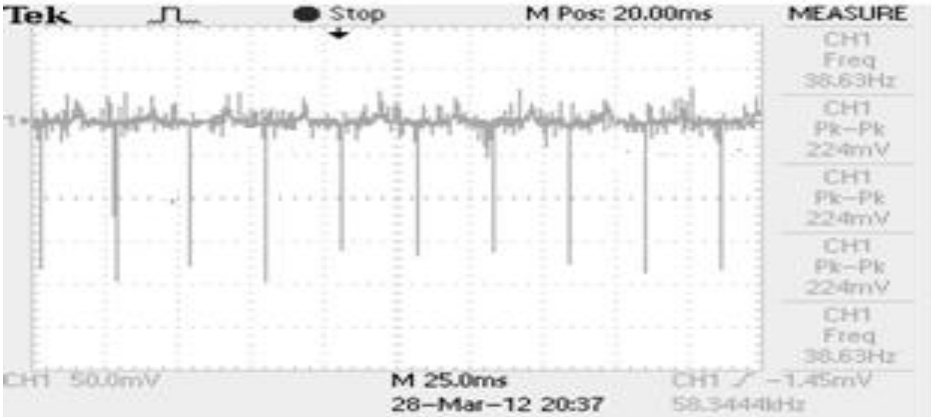

Figure 5: Generator supplying 169W

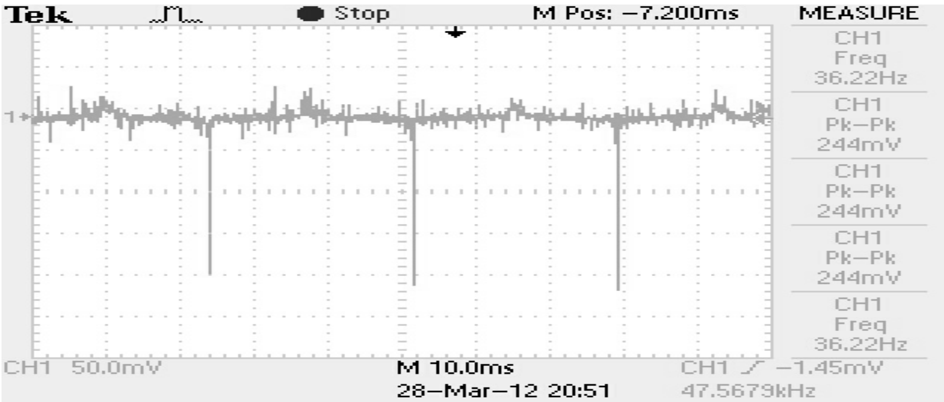

Figure 6: Generator supplying 204W

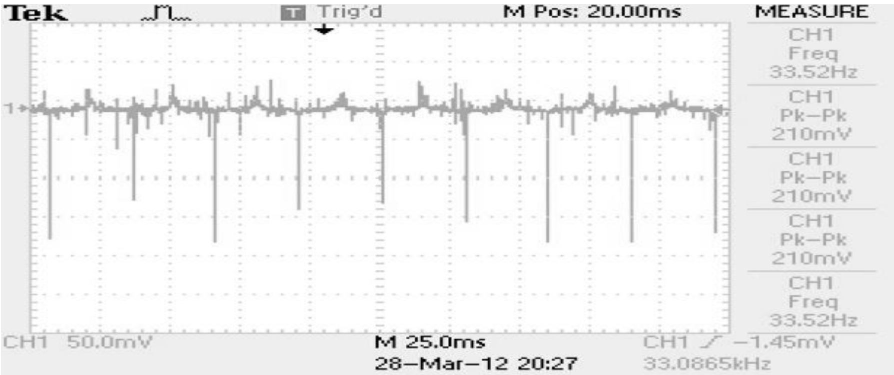

Figure 7: Generator supplying 220W

Figure 2 shows the MAW signal on no load, this is when the generator is spinning but not connected to any load (generator terminals open circuited). Figure 3 and figure 4 shows the results with generator supplying a load of 82.1W and 135 W respectively. In Figure 3, the frequency drops from 55Hz in figure 2 to 45Hz. This is due to the fact that for a DC series motor, the speed and hence the frequency drops with loading perfectly simulating isolated generator without a governor.

In figures 4, 5, 6 and 7, the frequency drop is more gentle, this is because the prime mover is taking a portion of this load as its torque increases (there is increase in current taken by prime mover), this is not expected in a typical Pico-hydro plant where water flow is assumed constant in this case but may vary but not in response to the load.

In all cases shown, the frequency continues to drop as generator load is increased. Other methods of frequency measurements that are included in this work are; calculating the frequency from speed measurements using tacho generator and equation (2), when the number of poles of a machine is known and direct measurement using frequency meter. These are well known methods that are used to measure the frequency of generation. From these, the results obtained from MAW and those from these methods are compared and presented as shown in table 1 and represented graphically in figure 8.

It is also very important to note that the generation frequency as read from the MAW has no direct connection with the generator and or the motor. This means that the frequency read by the sensor is very independent and gives its independent assessment

As seen from the table 1 the frequency obtained from generation meters, the calculated value from the equation 2 using speed measurements and the measured frequency read by the MAW and shown in the digital oscilloscope, closely match as can be seen on the frequency against power curve in figure 8. The frequency reduced from the peak value of 55Hz at no load to a low value of 33Hz when supplying 224W. This is a very big drop in frequency and such drops are not allowed in actual power system. This reduction in frequency is as a result of increase in generator loading.

Generated voltage is a function of frequency and field excitation as can be seen from equation 1. But for this case, the excitation is set at a fixed value hence the only other factor that affects it is the speed which is in itself a function of frequency. This causes voltage to drop as the frequency drops. A plot of generated voltage against frequency in Figure 9 shows that the generated voltage of the isolated uncontrolled generator increases with increase in speed and hence frequency.

In figure 9, it is seen that there is a very big drop in frequency from 55Hz on no load to 45Hz at minimum load; this is so because for a DC series motor at no load, the speed can increase to a point of self destruction. This machine has very low torque hence when loaded, speed drops as torque is built resulting in a very big drop in frequency. The torque equation is given by the following equation

$$T = K\varphi I_A \tag{3}$$

Where

- K Machine constant
- T Torque
- φ Flux
- I_A Armature current drawn.

From this equation it is evident that the torque of the prime mover increases with the increase in motor current. But again for a DC series machine, field current is the same as armature current (which affects flux) this explains the sharp drop in frequency that is seen on the graph since its effect is a square function.

Motor input quantities				Frequency Measurements			Generator ac output quantities			
Voltage (V)	Current (A)	Power (W)	Speed (rpm)	Calculated frequency using Speed	Measured Frequency using meter (Hz)	Measured Frequency using MAW (Hz)	Voltage (V)	Current (A)	Power (w)	Resistance (Ω)
244	0.9	220	3300	55.0	54.3	54.36	270	0.000	0.0	open
242	1.1	266	2800	46.7	45.2	45.05	263	0.104	82.1	2400
240	1.3	312	2500	41.7	41.2	41.45	234	0.192	135.0	1200
240	1.4	336	2300	38.3	38.5	38.63	213	0.264	169.0	800
240	1.6	384	2200	36.7	36.7	36.43	198	0.325	193.0	600
238	1.7	405	2100	35.0	34.7	36.22	184	0.370	204.0	480
239	1.8	430	2000	33.3	33.4	33.52	171	0.428	220.0	400
239	1.9	454	1900	31.7	32.2	32.41	162	0.463	224.0	343

Table 1: Results as collected and calculated from the experimental set up

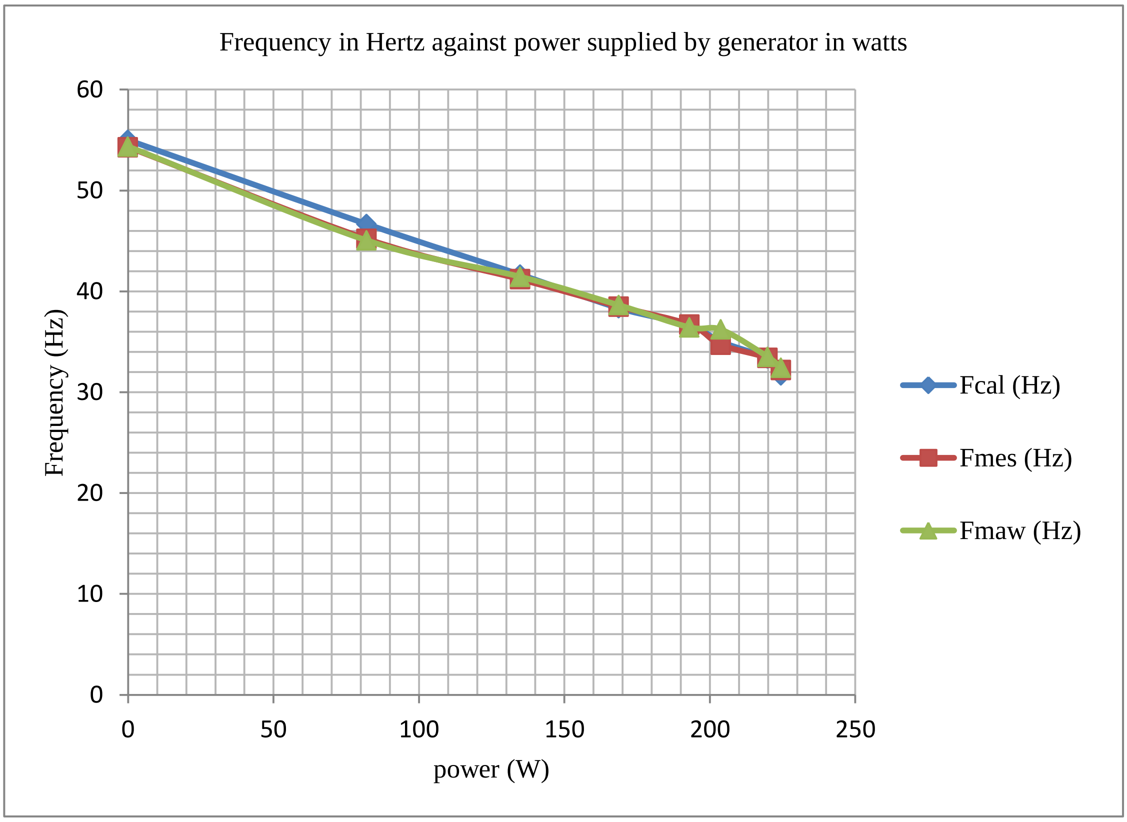

Figure 8: Frequency against power supplied

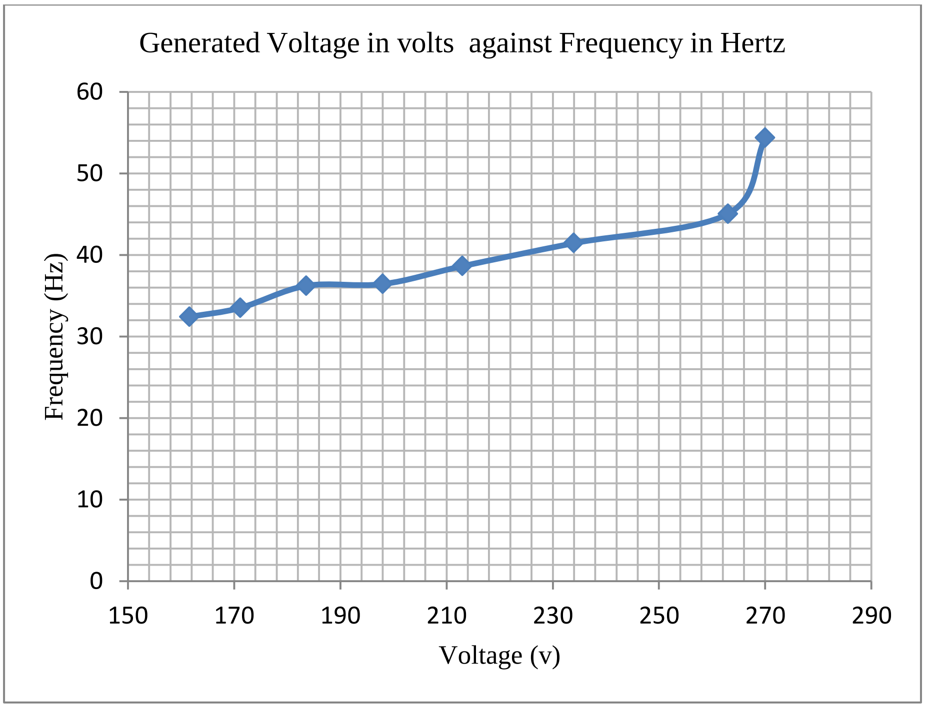

Figure 9: Frequency against generated Voltage

CONCLUSION

In this work we have shown that

(i) The frequency of uncontrolled generator can be measured using MAW which senses its frequency despite not having physical connection with the generator and or the prime mover.

(ii) Generation frequencies of an isolated turbine can be sensed for possible control action with the help of MAW

REFERENCES

[1] Stephen J. Chapman, "Electric machinery fundamentals," in *Electric machinery fundamentals*. Sydney, Australia: Mc Graw Hill, 2005, ch. 5, p. 272.

[2] Alexandra von Meier, *ELECTRIC POWER SYSTEM, A conceptual Introduction*. Hoboken , New Jersey, USA: A JOHN WILEY & SONS, INC., PUBLICATION, 2006.

[3] J. N. Nderu, P.K.Kihato and G.M. Hinga "Effects of motor cage temperature on motor speed sensing charateristic of magnetostrictive amorphous wire," in *IEEE AFRICON* , Nairobi, 2009, pp. 1-5.

[4] Bhim Singh, S. S. Murthy, Manish Goel and A. K. Tandon "A steady State Analysis on Voltage and Frequency control of Self Excited Induction Generator in Micro Hydro System," in *IEEE*, New Delhi, 2006.

[5] A.M. Muhia, J.N. Nderu, P.K. Kihato and C.K. Kitur"Performance of Magnetostrictive Amorphous Wire sensor in speed measurement," Jomo kenyatta University, Nairobi, Seminar 2011.

[6] Bhag S Guru, *Electric machinery and transformers / Bhag S. Guru. Huseyin R. Hiziroglu,.* 3rd ed. New York, USA: Oxford University Press, Inc., 2001.

[7] J. N. Nderu and P. Ruirii, "Speed sensing by amorphous magnetostrictive wires," *5th International Annual Mechanical engineering Seminar (JKUAT),* June 2000.

[8] B.L. Theraja and A.K. Theraja, "A Textbook of Electrical Technology," in *A Textbook of Electrical Technology*. New Delhi, India: S. Chand & Company Ltd, 1996,

Solar Energy Industry Future Uncertainty- An Opportunity for New Markets and Refocusing

Hattie Carwell,
MAAT Science Village, 4622 Meldon Ave, Oakland, CA 94619, USA
hattie.carwell@att.net

Keywords: solar energy, globalization, market expansion, Africa

Abstract

The 2012 solar panel pricing war between manufacturers in China, Europe and United States accompanied by the sales market slowdown due to government subsidies cuts has produced uncertainty in the future solar growth. A solar panel glut has resulted. Companies are pressured to push sales to protect their bottom-line. Sales goals are not necessarily aligned or tied with those of governments. This may become an opportunity to expand the solar power industry into emerging industrial powers that have been marginally involved. Emerging industrial powers such as Brazil, Australia, Argentina, South Korea, India, Indonesia, Saudi Arabia, Turkey, Mexico, South Africa and some other African countries are the likely expansion targets. All have plenty of solar radiation, a growing electrical demand and government leaders highly motivated to support solar energy. This paper will discuss the future expansion of the solar industry led by big business profitmaking interests rather than national needs. Business is focused on centralized solar facilities for large urban areas. It shows little interest in projects directed towards small cities or remote rural villages off the grid. This paper focuses on Africa because of its energy challenges make it most vulnerable.

Introduction

During the last decade, the solar energy industry experienced accelerated growth based on a hand full of zealous nations including Germany, Spain, Italy, Japan, United States, and China using an aggressive capital intensive global market approach. International companies funded by venture capitalists, and encouraged by government subsidies emerged. They fashioned the solar industry into multi-billion dollar businesses. The government subsidies have made solar energy more competitive with conventional methods of electrical generation. Also, the robust solar energy market switched the business installation focus from local small residential projects to large scale utility size projects that generate 100's of MW of electricity for urban consumption. Such projects led to large scale solar panel production factories built in remote locations and offshore to access cheap labor to minimize manufacturing costs. China had less than 1% of the solar panel manufacturing market in 2001 and now has 62%. It focused on solar panel production and significantly reduced costs.

In 2008, the world economic crisis which continues today, severely constrained access to credit and capital. Impacted, the United States, Japan and some European countries slowed down their capital intensive efforts to push the solar industry. Large Solar panel factories cost on average a $100 million and utility scale projects cost $1-2 billion. Most countries could not afford to keep up the investment pace. Germany and China were less impacted by the crisis and gained an edge. Germany continues to push government subsidies and now has more than 5 times as much solar energy power installed than any other country. China used its financial advantage (the 2nd largest world economy) to rapidly expand its manufacturing capabilities. Solar is its biggest industries and it exports 99% of its product. Five of its 400 manufacturers are among the top 10 in the world and China produces 62% of the world PV modules. China PV panels are the cheapest. It supplies 74% of the solar panels used in the US and 30% in Germany. Today, no other country has more than 9% of the solar panel production market. The United States, Japan and Germany have large solar manufacturing capabilities, but are struggling to compete with China's prices. Expansion of the market to other countries with large utility scale projects is the primary way these competitors are seeking to stay in the solar game. However, large scale utility projects to serve urban areas may not be the answer for those countries that are not highly industrialized, and with more than 50% of their populations living in sparsely populated rural areas without electricity. This paper will look at the future direction of the solar industry led by big business vs national needs to electrify rural areas.

Background Information on the Development of the Solar Industry

Germany initiated the solar incentives model and others developed their own variation. The residential solar market grew slowly. Once businesses and venture capitalists found that large profits could be made by scaling up projects as utility size power plants, residential solar lagged. Government agencies, and large electricity users are now the preferred customers.

Germany	Italy	Japan	U.S	Spain	China	France	Belgium	Czech Republic	Australia	All Others
24.82 GW	12.8GW	4.93GW	4.4 GW	4.27GW	3.1GW	2.66 GW	2.0 GW	2.0GW	1.34 GW	6.2 GW

Table1. Over 100 countries use solar power. Provided is the solar capacity for the top ten as of 2011.[1]

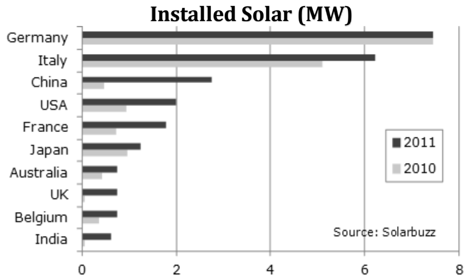

Figure1. Solar installed in 2010 and 2011[2]

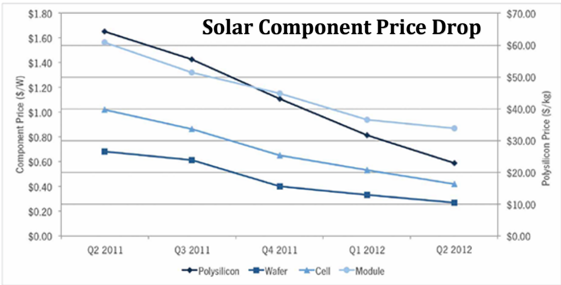

Figure2. Solar Cost Reduction by solar component[3]

As the demand for solar grew, manufacturers dramatically reduced solar production costs with large scale production techniques and competitive pricing. The price of PV systems in Europe decreased more than 50% in 5 years since 2006.[4] While these price drops are beneficial for the end user, the sharp fall in prices, driven in part by a global oversupply, has put a serious strain on solar manufacturers' profit margin worldwide. The global capacity at the end of 2011 was 69 GW. See Table 1.

Growing New Markets

Currently, the U.S. and Germany are struggling to find sales for their solar panels because of the market glut. To stay in the solar business, businesses need to create new markets beyond their borders. Countries new to the G18 and developing countries that have played a marginal role in the solar market are the prime targets.

Whereas, governments have led the way to grow the solar market, now businesses are leading. Whereas, governments have based their decisions to go solar to support their socio-economic goals to add clean and renewable energy to their energy mix, a paradigm shift has taken place where external business strongly influence the goals and determine whether they are met. The tables are turning in the expanding the market. Rather than governments incentivizing solar businesses to grow the market, solar businesses and investors are incentivizing governments to grow the market. Businesses have been laying the groundwork to enter the growing markets predicted by the UN, World Bank, and African Development Bank reports. Many potential new markets lack finances to enter the solar market. Therefore, big businesses are promoting sales by offering attractive finance deals.

H.E. Dr. Jean Ping, then Chairperson of the African Union Commission indicated in 2009 that compelling evidence from different countries in Africa and elsewhere show that renewable energy systems, both small and large-scale are part of the energy solution of the continent. He encouraged policy makers, therefore to send a strong signal to all development partners of their commitment to the development of renewable energy resources as part of the process of developing the continent. Likewise, the international community is equally called upon to rise to the challenge and ensure that renewable energy resources on the continent significantly contribute to the energy mix.[5] The development of sustainable and long-term solutions to meet the growing, diverse and urgent energy challenges assumes special significance for developing countries in general and countries in Africa in particular.

Country	Project and Compl. Year	Rural Impact	R-Energy Strategy	Financing	Manufacturer	Tech Transfer
Mexico	450MW	None	Limited gov. initiated projects	USA Private Sector U	Manu. USA/Japan Panels	No. Does not Control Industry Serves as Low cost workforce
India	619 MW 2012 Resident Solar	None Yes	Yes	Government incentives UNEP Loans	Self Import	Yes No
Cambodia	Design/ Manu. Small Home Systems	Goal-100 % grid quality Elec. By 2020	15% of rural electricity -solar and small hydro by 2015	Donor and private bank loans; Government incentives	Self- Product Development	Yes
Rwanda	250 kw (2008) 200kw Portable solar powered prod.	None Rural Clinics, Schools, Gov. Admin. Bldg.	Expand Grid Decentralize Electrification	Funded by Germany Gov. and NGO, World Bank, EU, Belgium	German	Product user
South Africa	238 MW 3 project	None	Yes (2010)	USA Private Sector	USA - Solar Reserve	PPA
Namibia	500MW (2014)	None	Limited	USA Private Sector	USA	PPA
Cameroon			Yes (2012)			
Nigeria	Solar Tele Com	Target Popula.				
Ghana	50MW 300MW	None None	Yes. 10% renewable-2020	Canada-Epic Solar, Inc.	Small Plant in Ghana	Limited; Small manu ; PPA
Sierra Leone	Solar H_2O Pumps Solar Barefoot College	Yes	Yes; small scale	Government /UNEP	Imported	Limited
Kenya	Solar Water Pumps/Solar Hot water 50 MW	Yes Urban	Yes	Government Initiatives	Imported	No

Table2. Solar Projects in new solar markets previously marginally involved.

Africa continues to face critical challenges related to its energy sector. The current energy policies and systems have failed to provide the platform needed to support the economic development of the majority of Africa's poor. In fact, energy has been supplied in insufficient quantity, at a cost, form and quality that has limited its consumption by the majority of Africa's population. The continent has the lowest per capita consumer averaging about 0.66 Tons of Oil Equivalent (TOE) compared to the global average of 1.8 TOE in 2008. Over the past four decades, the gap between energy supply and demand in Africa has actually widened, while it has narrowed in other developing countries. Unless drastic interventions are made, recent trends indicate that this gap will continue to grow, and the majority in Africa will continue to lack access to basic energy services and hence would have limited chances of realizing any meaningful social and economic development.[6] As the unique multilateral financing institution dedicated exclusively to Africa, the African Development Bank (AfDB) is in a position to take on the role of providing coordination, brokerage and syndication services to Regional Member Country (RMCs), bilateral and multilateral institutions, and private development partners.

According to the AfDB, a country should meet four pre-requisites to develop a successful energy plan. These are 1) a clear strategy; 2) an institutional framework of policy, regulations and incentives 3) information and technology capacity 4) appropriate financial instruments and finances. Most of the sub- Saharan African countries do have all four. The scaling up of renewable energy to levels that would have a significant impact on the continental energy scene could be achieved through deliberate interventions on policy and institutional environment; technology acquisition, development and integration; investment mobilization; and regional integration, networking, and capacity building. Policy makers in Africa are recommended to recognize the potential role of renewable energy in meeting the energy challenges being faced by the region, and assume a proactive role in implementing the recommendations. There is an urgent need to assume an integrated and coordinated approach at a regional level to scale up the deployment of renewable energy technologies so as to increase access to modern energy services and increase energy security to support economic and social development.[7] Countries tend to prefer to go it alone.

It is paramount that solar electrification policies strike a balance between large scale systems for urban areas and small scaled systems for rural households and small scale commercial installations. Geographical realities suggest that decentralized autonomous energy infrastructure development harnessing local resources – most often, renewable – is a more cost-effective approach to increasing rural energy access. On the other hand, integrated national power grids and fuel bulk supply systems interconnected at the regional or multi-country level are the most cost-effective and reliable means to meeting the energy needs of urban populations and economic sectors.

The total number of individuals without electricity, roughly, 1.5 billion people or a quarter of the world's population, concentrated mostly in Africa and southern Asia more than likely will not be touched by the large solar scale projects.[8] On average, only 11% of the African rural population has access to electricity. Compared to other parts of the world, energy deprivation or the lack of access to energy is most prevalent by far in Africa. Access to the electricity grid in many Sub-Saharan countries is less than 1%.[6] Recent trends indicate that over 60% of Sub-Saharan Africans will still not have access to electricity by 2020.[7] The United Nations General Assembly declared 2012 the International Year of Sustainable Energy for All. Access to modern affordable energy services in developing countries is essential for the achievement of the internationally agreed upon development goals, including the Millennium Development Goals (MDG). Sustainable development would help to reduce poverty and to improve the conditions and standard of living for the majority of the world's population.

Businesses and investors are pulling together financial packages and purchase service agreements that make $1-2 billion utility scale projects possible in these countries where the finances are not available. The manufacturers and their partners are looking for customers that can make the effort worth their while. Therefore, their focus is to make the sale and maintain control of the solar industry. Most proposals can be best described as technology import and not technology transfer. Attracting private sector financial involvement has dominated the focus of power sector reform orientation, thereby prioritizing profit while neglecting the need to electrify rural areas, one of the UN MDGs.

The German and U.S. solar manufacturers promote projects to governments closely resembling those built in their own country with little consideration of the differences in markets. Very little leeway for local solar industry capacity building and customer focus is given. The country is relegated to technology consumers and not developers. Financing is designed to have a boomerang effect. The financed money goes back to the financer who is also designing, building and supplying the equipment. Only a very small portion of the money goes into the local economy. Job creation and technical skills transfer are limited.

For example, in Mexico, SolFocus Inc., a San Jose California solar manufacturer founded in 2005 plans to help build a $1.5 billion 450 MW solar concentrator power plant near Tecate, along the California border. The plant is not a response to a government energy plan, but rather a partnership between the company and a local developer as a business enterprise like the one in the California Mohave Dessert. The intent is not only to provide Mexico with power, but also possibly sell power to California. [9]

The U.S. is working with South Africa. The South Africa Department of Energy (DOE) awarded a 88 megawatt (MWDC) photovoltaic (PV) project with preferred bidder status to the consortium of SolarReserve, a U.S. developer of utility-scale solar power projects, the Kensani Group, an experienced empowerment infrastructure player in the Southern African market, and Intikon Energy, a South African developer of renewable energy projects. Three projects totaling 238 MW account for a 20 percent share of South Africa's solar market. [10]

A power purchase agreement signed by the Nambian government with the American investment group led by Washington-based project developer SSI Energy Solutions (SSIES), is the parent company of Africa Energy Corp. set up for the Namibia project. Partners in the project include former SunEdison CEO Jigar Shah, Tom Amis and Nik Patesh of clean-energy law firm Cooley LLP, Eric Henderson of the Beacon Group and Adam Stern and Gary Kleiman of The Gemstone Group and Engineering, and the Engineering Procurement and Construction (EPC) contractor promotes consumerism and energy dependency. The project will not benefit the majority of Namibians in rural areas. [11]

Purchase agreements create dependency on external businesses and can jeopardize the country’s energy security and cripple local capacity building by suppressing prices to artificially low levels. They also curtail local participation in the full solar socio economics (jobs creation, manufacturing, financing, and restrict electrification to urban areas). Locked into rates long-term, countries cannot take advantage of market rate drops.

Below is an example of solar projects led by India to fit their energy strategies and designed to result in technology transfer. According to a 2011 report by GTM Research and BRIDGE TO INDIA[12], India is facing a perfect storm of factors that will drive solar photovoltaic (PV) adoption at a "furious pace over the next five years and beyond." The falling prices of PV panels from China and U.S., has coincided with the growing cost of grid power in India. Government support and ample solar resources have also helped to increase solar adoption, but perhaps the biggest factor has been need. India, "as a growing economy with a surging middle class, is now facing a severe electricity deficit that often runs between 10 and 13 percent of daily need.” The Charanka Solar Park, 214 MW was commissioned on April 19, 2012, along with a total of 605 MW in Gujarat, representing 2/3 of India's installed photovoltaics. The Guijarat state developed its own solar policy, obtained financing from the Asian Bank and services of many Indian companies. It is aggressive in the development of the solar industry including research and innovation.

Examples of Solar Rural Electrification Projects

Unlike the past decade, which saw solar solutions purchased mainly by international donors, it is now the locals who are increasingly opening their wallets to make the switch from their traditional energy means. That is because solar products prices in recent years have declined to become cheaper than kerosene and batteries.

In Cambodia, for example, villagers can buy a solar lantern at US$25 and use it for years without any extra costs, where their previous spending on kerosene for lighting was about $2.5 per month, or $30 per year. In Kenya a solar kit that provides bright light or powers a radio or cell phone costs under $30 at retail stores. Switching to this kit Kenyans can save $120 per year on kerosene lighting, radio batteries and cell phone recharging fees. Developing countries where many villages are often more than five-- kilometers away from grid power are increasingly using photovoltaics. In remote locations in India a rural lighting program has been providing solar powered LED lighting to replace kerosene lamps. The solar powered lamps were sold at about the cost of a few months' supply of kerosene. In 1993, the Cuban government committed to electrify rural schools. Lack of access to foreign oil due to embargoes made it necessary for Cuba to develop their own solar manufacturing industry to provide affordable electrical power for areas that are off grid. Today, over 2,364 schools, 350 doctors' offices, and hundreds of hospitals draw their power from silicone-based solar panels. According to Bruno Henríquez of Cubaenergia, "There is currently a plan to electrify 100,000 more rural households at a rate of 20,000 per year."These are areas where the social costs and benefits offer an excellent case for going solar though the lack of profitability could relegate such endeavors to humanitarian goals.

Kumba, Cameroon (AlertNet) Â¿ Cameroon has had some early successes with bringing solar power to families, particularly in the country's southwest Kumba region where a non-profit local effort is already reaching 50,000 people.

Funding Sources to Support Small Scale Rural Projects

European countries that consume oil refined from African countries have the opportunity to subsidize the costs of individual level, village level, or community level alternative energy systems through emissions trading credits. It has been proposed that for every unit of African origin carbon consumed by the European market, a predetermined amount green credits or carbon credits would be yielded. The European partners could then either supply parts, components, or systems directly, an equivalent amount of investment capital, or lend credits to finance the distribution of renewable energy services, knowledge or equipment. International relief targeted at poverty reduction could also be redirected towards subsidizing renewable energy projects. Because of the integral role that electrification plays in supporting economic and social development, funding of rural electrification can be seen as core method for addressing poverty and providing information services. Because information services allow for the proliferation of education resources, funding the electric backbone to such systems has derivative effect on their development.

UN Energy Program (**UNEP**) is an international institution or program assisting developing countries in implementing environmentally sound policies and practices. (UNEP) has developed a loan program to stimulate renewable energy market forces with attractive return rates, buffer initial deployment costs and entice consumers to consider and purchase renewable technology. After a successful solar loan program sponsored by UNEP that helped 100,000 people finance solar power systems in developing countries like India, UNEP started similar schemes in other parts of developing world like Africa - Tunisia, Morocco, Kenya projects are already functional and many projects in other African nations are in the pipeline. In Africa, UNEP assistance to Ghana, Kenya and Namibia has resulted in the adoption of draft National Climate Awareness Plans, publications in local languages, radio programs and seminars. The African Rural Energy Enterprise Development (AREED) initiative is another flagship UNEP effort focused on enterprise development and seed financing for clean energy. AREED1offers energy entrepreneurs in Mali, Ghana, Tanzania, Senegal and Zambia a combination of enterprise development services, as technical support and, early stage financing to promote small, sustainable energy ventures. This integrated financial and technical support allows entrepreneurs to plan and structure their companies for growth and makes eventual investments by mainstream financial partners possible.

Although solar power technology has the potential to supply energy to large numbers of people, and has been used to generate power on a large scale in the U.S. and other developed nations, its greatest potential in Africa may be to provide power on a smaller scale and to use this energy to help with day to day needs such as small-scale electrification Projects.

Conclusion and Next Steps

The Solar Energy Industry led by Germany and China has become a capital intensive business focused on large scale utility size projects. Competitors are seeking new markets and promoting large scale projects in developing countries. Large scale solar electrification projects are not suitable for rural areas that are sparsely populated and remote. Limited attention is paid to this segment of the solar industry. Development of human and institutional capacities to cope with the manufacturing, operation, and modification of renewable energy technologies is critical. This situation is a great opportunity for small enterprises to develop affordable solar products to people without electricity to improve their standard of living. Also, it is an opportunity for small companies or social entrepreneurs such to acquire a niche in designing modular solar systems scaled to meet small household electrical needs or community cooperatives to create solar micro grids.[13] Some the rural electrification projects that are donor funded or seeded by UNEP money can be replicated and expanded into additional rural communities to provide local job opportunities for economic development. This can be achieved with modest capital investments. Next steps are to connect communities with social entrepreneurs to focus on rural electrification.

References:

[1] “Solar Installed Capacity for 2011.” Energici, August 29, 2012.

[2] Ibid.

[3] “Executive Summary.” Solar Market Insight Report:Q2 2012, September 12, 2012, p.10.

[4] “Evolution of Support Schemes for PV Generated Electricity: Recommendations to Policy makers.” European Photovoltaic Industry Association,· Brussels , Belgium , August 4, 2011:1

[5] Ping, H.E.Jean, “Scaling Up Renewable Energy in Africa” 12th Ordinary Session of Heads of State and Governments of the African Union, Addis Aba, Ethiopia, January 2009: 4.

[6] Ibid, p.7.

[7] "*Clean Energy Investment Framework for Africa: Role of the AfDB Group."* Proposals for A Clean Energy Investment Framework for Africa Role of the African Development Bank Group**,** Final Version, Operations Policies and Compliance Department, Tunis April 2008.

[8] Gronewold, Nathaniel. "One-Quarter of World's Population Lacks Electricity *Scientific American* November 2009:

[9] SolFocus to Help Mexico Build 1st Big Solar Plant (last checked October29, 2012). http://www.sfgate.com/business/article/SolFocus-to-help-Mexico-build-1st-big-solar-plant-3443752.php#ixzz2Akd1EUCQ

[10] South Africa Department of Energy Awards Additional Large-Scale Solar Project to Consortium of SolarReserve, Kensani and Intikon Energy (last checked October 29,012). http://www.prnewswire.com/news-releases/south-africa-department-of-energy-awards-additional-large-scale-solar-project-to-consortium-of-solarreserve-kensani-and-intikon-energy-152919425.html

[11] Pre-Feasibility Study for the Establishment of a Pre-Commercial Concentrated Solar Power Plant in Namibia, September, 2012 (lasted checked October 30, 2012) http://www.reeei.org.na/cps/cps_/CSP PRE-FEASIBILITY STUDY.EXECUTIVE SUMMARY.pdf

[12] "The India Solar Market: Strategy, Players, and Opportunities." GTM Research and Bridge to India November 2, 2011 (last checked October 30, 2012) https://www.greentechmedia.com/research/report/the-india-solar-market-strategy-players-and-opportunities/

[13] A Billion People in the Dark, MIT Technology Review (last checked October 30, 2012) http://www.technologyreview.com/featuredstory/429529/how-solar-based-microgrids-could-bring-power-to-millions/

SUBJECTIVE WELLBEING AND SUSTAINABILITY: A DATA DRIVEN LOOK AT GLOBAL ELECTRIC ENERGY CONSUMPTION

Marcel J. Castro-Sitiriche[1] and Mandoye Ndoye[2]
[1*]Department of Electrical and Computer Engineering, University of Puerto Rico, Recinto Universitario de Mayagüez, Mayagüez, Puerto Rico, marcel.castro@upr.edu.
[2]Center for Applied Scientific Computing (CASC), Lawrence Livermore National Laboratory, Livermore, California, USA, ndoye1@llnl.gov.

Key Words: Appropriate technology, electric energy access, subjective wellbeing, sustainability.

ABSTRACT

Access to electric energy is one of the drivers of wellbeing and universal access to energy has recently been identified as an important goal in the international community. A data-driven analysis of electric energy consumption and subjective wellbeing indicators is introduced to promote a broad conversation about relationships between energy poverty, global equity, subjective wellbeing measurements and good quality of life. The electric energy consumption has been related to social progress using Human Development Index (HDI) data. The proposed approach goes beyond using HDI: It directly focuses on the overall goal of attaining good and long lasting lives. The concept of human flourishing is the main pillar of terms such as human wellbeing, quality of life, and social progress. The other crucial concepts concern the implications for future generations, the importance of ecosystems in enabling sustainable wellbeing and the capabilities in communities to flourish in the long term. A community based approach led by higher education institutions is proposed to jump start a long term change that begins with a vision for sustainable wellbeing. Eventually, the proposed pathway should lead to a capabilities approach assessment for appropriate technologies, with special emphasis on electric energy consumption. The results point out that although there is an important relationship between electric energy consumption and human wellbeing, a deeper look at electric energy access, different subjective wellbeing indicators, local capabilities enhancement, and participatory decision making processes is needed to better prepare long term energy plans at the local and global level. If this important work is left undone, many well intentioned efforts will not serve well the people in the communities whose lives are supposed to be improved by ongoing and future initiatives.

"Creating sustainable energy access for all will be one of the great challenges of this century. To achieve it will require a step change in the efficiency and equitability of human organization. This will take bold leadership, and leverage of the skills and resources of people and organizations all over the world. But we believe it is possible, and 2012 should be the launch pad for an energy access revolution."

Poor people's energy outlook 2012: Energy for earning a living, Practical Action, UK [1].

INTRODUCTION

The access to electric energy has become one of the main ways to improve the quality of life in poor communities. The universal access to modern energy has been recognized by the United Nations as an important goal. As such, international efforts to achieve it like the *Energy for All 2030* and the *Sustainable Energy for All* Campaign have been launched. The United Nations General Assembly declared 2012 the year of *Sustainable Energy for All* stating that "…access to modern affordable energy services in developing countries is essential for the achievement of the internationally agreed development goals, including the Millennium Development Goals, and sustainable development, which would help to reduce poverty and to improve the conditions and standard of living for the majority of the world's population" [2]. Furthermore, organizations directly focusing on appropriate technology such as Practical Action have launched similar initiatives with special emphasis on energy poverty and poor people access to energy [1]. A seminal work by Alan Pasternak [3] focused on the relationship between electric energy consumption and the Human Development Index (HDI), which is used in the yearly United Nations Human Development reports. However, the HDI has been criticized for not including factors that measure subjective wellbeing and the environmental impact countries have in their local and global ecosystem. The first criticism has been directly acknowledged in recent reports [4], which recognized the relevance of subjective wellbeing for human progress. The last criticism has been firmly established when a template for a new Human Sustainability Index was presented at the 2012 UN Conference on Sustainable Development [5] in Río de Janeiro, Brazil. Both issues have been previously pointed out by the New Economics Foundation think-and-do tank [6], based in London, that has proposed an efficiency index of sustainable wellbeing [7].

Efforts to include the assessment of ecosystem condition along with the human wellbeing have been taking prominence within the scholarly researchers in the last ten years [8]. This has led to the general consensus that underscores the pressing need of using a systems approach when studying the relationship between the natural ecosystem and the quality of life [9]. The Millennium Ecosystem Assessment group was established "to assess the consequences of ecosystem change for human well-being and [to establish] the scientific basis for actions needed to enhance the conservation and sustainable use of those systems and their contributions to human well-being" [10].

The current approach focuses on the analysis of global data to relate different measures of wellbeing with electric energy consumption and other variables that directly impact the environment. Previous works that focused on the relationship between electric energy consumption [3] and carbon dioxide emissions [11] with the HDI are used as foundations for this work, which extend them by including subjective wellbeing measures as the main indicator of human flourishing and social progress.

METHODOLOGY

The main theme of the work is based on the thesis that measures of sustainable human wellbeing can provide meaningful information to assess improvement of the quality of life in communities now and in the future. While it appears quite obvious that to facilitate the improvement in one particular area the best way to assess it is with measures within that particular area, in practice, this is not the case for many areas. Two prominent examples are related to government and technology/engineering. While few would oppose the view that the role of the government is to facilitate the best possible quality of life for society, few governments actually have a well established national accounts of wellbeing [12]. Likewise, technology definitions usually include a sense of satisfying human needs and improving life. The engineering profession is similarly tied to human needs and the improvement of the quality of life, which puts a heavy responsibility on the engineer [13] [14]. To promote the discussion of human wellbeing measures as they relate to the engineering enterprise and technology, a brief look into global electric energy consumption and subjective wellbeing is presented. Subjective wellbeing has been identified as one of the leading measures of progress [12] and life satisfaction is proposed as the main measure of progress [15]. However, there are different ways to approach the issues of social progress, happiness, quality of life, wellbeing and human flourishing [6] [16] [17] [18] [19] [20]. Table 1 provides a compact summary of important terms used. The proposed methodology starts by looking at a variety of wellbeing measures and potential drivers of wellbeing focused on energy consumption. However, a similar approach needs to also be applied to other areas such as access to clean water, nutritious food, broad education, and safe housing. Other important indices and measures that have been developed include the Genuine Progress Index, Gallup

Wellbeing Index, Sustainable Economic Welfare Index, Gross National Happiness, Social Life Cycle Assessment, Social Return of Investment, Capabilities Approach, and Fair Allocations Approach.

Table 1. Human wellbeing, ecosystems, and electric energy consumption terminology

Term	Description
Life Expectancy (at birth)	Number of years a newborn infant could expect to live if prevailing patterns of age-specific mortality rates at the time of birth were to stay the same throughout the infant's life. [4]
Subjective Wellbeing Measures	Measured by asking people about their experiences (their feelings and their interactions with the world) and about their judgments of those experiences. The two main questions used are the Cantril Ladder and Overall Life Satisfaction [6], [7], [21] [16]
Happy Life Years (HLY)	Combination of Life Expectancy and the normalized value of Life Satisfaction to obtain an approximate value of expected years lived satisfied [7], [21]
Ecological Footprint	The average per capita ecological footprint of a country is a measure of the amount of land required to provide for all their resource requirements plus the amount of vegetated land required to absorb all their CO2 emissions and the CO2 emissions embodied in the products they consume. This figure is expressed in units of 'global hectares' [21].
Human Development Index	A composite index measuring average achievement in three basic dimensions of human development — a long and healthy life, knowledge and a decent standard of living. [4]
Happy Planet Index	Index that measures the ecological efficiency with which happy and healthy lives are supported. As an efficiency measure it looks at the output/input relationship using the happy life years as the output and the ecological footprint as the input needed to obtain the desired output [7], [21].
Per Capita Electric Energy Consumption	Average per capita electric energy consumed in one year for the population of a country. Usual units are in kWh per year.
Per capita CO_2 Emissions	Average per capita emissions of CO_2 in tones.
Energy Intensity	Energy intensity indicates the efficiency of a country in converting energy consumption (kWh) into economic purchase power (Purchase Power Parity). The unit commonly used is MJ/$ and a higher value of energy intensity reflects a lower efficiency.

RESULTS

The data used for the analysis is publicly available from the following organizations: New Economics Foundation [7], United Nations Development Program [4], and the U.S. Energy Information Administration (http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=2).The graphical results provide a rich source of information that could be useful in many ways. A few uses of this information could have deep implications for policy decisions at a global level and also for community actions at the local level. For example, in Figure 1, the HLY of 152 nations are plotted against the Per Capita Electric Energy Consumption. The figure shows a logarithmic relationship similar to the results reported by Pasternak [3] and Spierre [11]. A possible use of this information is to identify nations that are leaders at different levels of electric energy consumption and study their success in converting electric energy, among other things, into long and happy lives, HLY. Three nations are identified in Figure 1 among three different per-capita consumption levels. Switzerland is the leader among the countries consuming more than 5000kWh per capita annually, while Madagascar leads the countries that consume less than 100kWh per capita annually. Costa Rica turns out to be the leader in its intermediate group of consumers between 100kWh and 5000kWh. Costa Rica is also the overall leader because its HLY is comparable to that of Switzerland while at the same time it is within the desired region identified earlier, less than 5000kWh and more than 50 HLY. Other nations that fall within the desired region are explicitly identified in Figure 2. Even though these are within the desired region, none of them are near the closer-to-target spot of 65 HLY and 2000kWh. This is analogous to the approach presented in the second Happy Planet Index report [21] in which a target average for OCED countries in 2050 of 70 HLY and 1.7 global hectares are proposed to achieve an average 89 HPI.

Another approach for using the data is to devise policy strategies for three groups of nations that could become the "groups of leaders". The first group is already the "global leader" with the pack within the desired region shown in Figure 2. The policy objectives should help these countries move toward the goal of 65 HLY and 2000kWh. The second and third groups could be named as potential “leaders of change” because their proximity to the desired region. The second group, shown in Figure 3, already has acceptable levels of HLY, but needs to decrease its electric energy consumption to enter the desired region. Even though the decrease in consumption needed is not large at all for this group, the general trend of increasing consumption due to an economic growth that is faster than improvements in technology efficiency would make it very hard for this group of nations to successfully decrease their consumption. Complementary strategies, such as the broad incorporation of renewable energy systems could help them overcome this challenge. To account for this, the Carbon Dioxide Emissions (See Figure 7) data will be helpful. The third group, shown in Figure 4, needs to slightly improve the HLY without increasing much of their consumption.

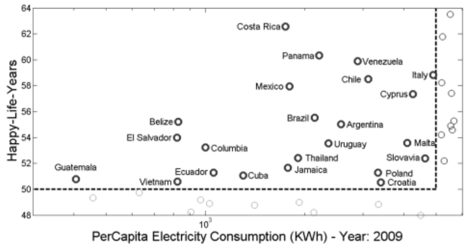

Figure 2. Desired Region: HLY vs. Annual Per-Capita Electric Energy Consumption (kWh)

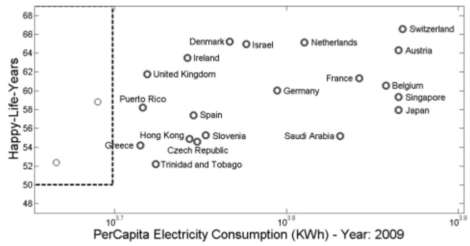

Figure 3. High Consumer Region: HLY vs. Annual Per-Capita Electric Energy Consumption (kWh)

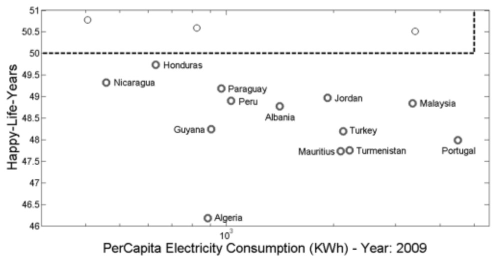

Figure 4. Low Consumer Region: HLY vs. Annual Per-Capita Electric Energy Consumption (kWh)

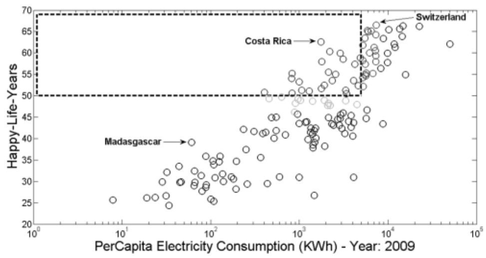

Figure 1. Happy Life Years (HLY) vs. Annual Per-Capita Electric Energy Consumption (kWh)

The third group seems to be in the best position to demonstrate a positive trend over the next decade for two reasons: 1) most have a relatively low consumption and could significantly increase it in order to improve life satisfaction and life expectancy and 2) showing a significant improvement in HLY at lower values is not as hard and slow as the process of increasing the HLY of a nation that already has a relatively high HLY. Among this group, Nicaragua and Honduras have the greatest potential to enter the desired region. However, this group is likely to face the challenge to overcome the access to financial resources that facilitates improvements in quality of life. Therefore, a policy strategy that requires a minimum of capital investment and focused on human capital could be the most desirable. Once some of these nations successfully become “leaders of change”, other nations could try to replicate the success of a country that best fits its own overall profile. For the replication process to be successful, detailed information on policy decisions and rigorous measures of progress need to be documented, analyzed, and disseminated. Existing tools and methodologies such as the Social Return of Investment, Index of Sustainable Economic Welfare, Social-LCA, and Benefit Assessment – LCA, could provide detailed data at a smaller scale to complement national accounts of wellbeing like those previously discussed.

Figure 5 shows the relationship between electric energy consumption and ecological footprint. It demonstrates that not even one of the countries that have an average annual consumption per capita above 2,000 kWh is within the earth biocapacity of 2.1 global hectares per person. The graph points to the fact that to achieve universal access of electric energy and to put an end to energy poverty is not enough because of the depletion of natural resources and the limits of ecosystems. The connection between the natural ecosystems and human wellbeing has been established [8] [10]. Figure 6 underscores the importance of considering other aspects, such as CO_2 emissions, that might have a direct or indirect impact on human wellbeing. Research led by Spierre made similar comparisons using the HDI as the measure of human wellbeing. That work emphasizes that the equity in carbon emissions allocations is a very important aspect that needs to be discussed in global debates [11]. Figure 7 shows the relationship between two efficiency indexes: the Happy Planet Index and the energy intensity. Two main points could be drawn from this plot: 1) a low energy intensity does not necessarily reflects an efficient conversion of natural resources into sustainable wellbeing, for example the case of Chad, and 2) there appears to be an energy intensity mid-range region in which the sustainable wellbeing is higher than in other regions. Previous studies provided the basis to further investigate the reason why a level of electric energy consumption higher than 4,000 kWh and low energy intensity value are not enough to guarantee a high HDI [3]. This fact points to the reality that access to electric energy and a relatively efficient process to convert that energy into GDP are not enough to facilitate "human development". Figure 8 shows the relationship between two human wellbeing indexes: the Happy Life Years (HLY) and the Human Development Index (HDI). The HDI has been used and cited in work that highlights the importance of access to electric energy to humanity. However, the HDI has its own limitations and the HLY provides a simpler and more robust alternative. While both indices prominently use the life expectancy at birth, the HLY is also supported by measurement of life satisfaction. Life Satisfaction has been identified as a crucial, if not the best indicator of human wellbeing [22] [15], [16], [6]. Because a strong correlation between the two indices exists, HLY could be used instead of the HDI and further explore the differences between them. One of the main advantages of using HLY lies in the fact that it focuses directly on desired outcomes, which is a long happy life, instead of the means to achieve them, such as GDP and educational attainment.

The next two plots are based on the land-based energy consumption density, an important aspect for sustainable energy pointed out prominently in recent work [23]. The importance of the electric energy consumption per unit of land area is directly related to the intrinsic physical limits that each type of energy resource. Some estimates of power per unit land area shows the difficulty in supplying the growing demand of energy per person for a growing population in a static land area planet. For example, wind power can provide from 2 to 3 W/m^2, solar power can provide from 5 to 20 W/m^2, and 11 W/m^2 for a hydroelectric power facility [24]. The relationship between per capita consumption and "per area" consumption of electric energy shows a strong correlation. The Figures 9 and 10 relate the land based energy consumption density to wellbeing (HLY) and sustainable wellbeing (HPI), respectively. The Figure 10 shows a clear pattern in which the HPI values are maximized at an intermediate level of energy consumption density, similar to Figure 7. The shape of this plot follows the essence of the concept presented by Meredith Thring [13] when establishing the relationship between sustainable quality of life and standard of living, and ideas promoted by economist such as Manfred Max-Neef [25], José Alameda and Ivonne Díaz [19].

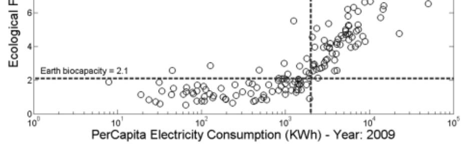

Figure 5. Ecological Footprint (EF) vs. Annual Per-Capita Electric Energy Consumption (kWh)

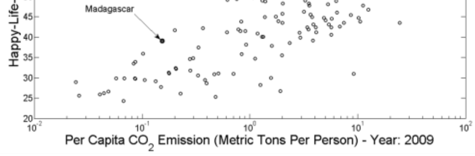

Figure 6. Happy Life Years (HLY) vs. Annual Per-Capita Carbon Dioxide Emissions (Metric Tons)

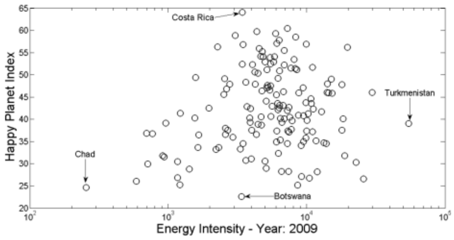

Figure 7. Happy Planet Index (HPI) vs. Carbon/Energy Intensity

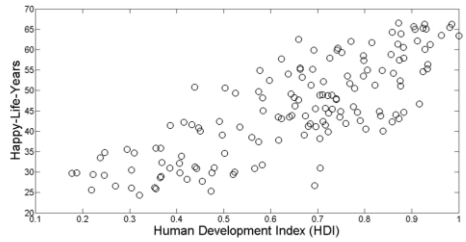

Figure 8. Happy Life Years (HLY) vs. Human Development Index (HDI) 2009

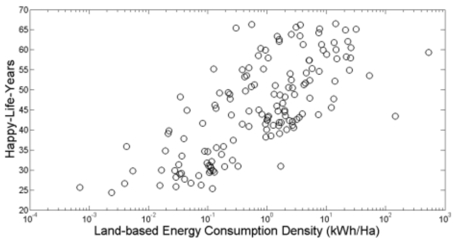

Figure 9. Happy Life Years (HLY) vs. Land-based Energy Consumption Density

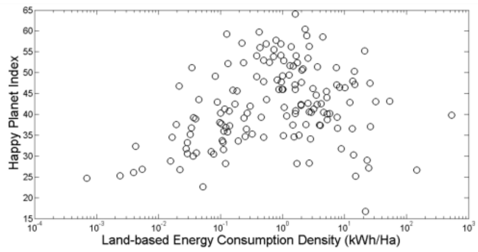

Figure 10. Happy Planet Index (HPI) vs. Land-based Energy Consumption Densi

FURTHER WORK

It has been reported that "there is *established but incomplete* evidence that changes being made in ecosystems are increasing the likelihood of nonlinear changes in ecosystems (including accelerating, abrupt, and potentially irreversible changes) that have important consequences for human well-being" [26]. One of the major gaps identified in the Millennium Ecosystems Assessment work has been stated as follows:

> "Models used to project future environmental and economic conditions have limited capability for incorporating ecological "feedbacks," including nonlinear changes in ecosystems, or behavioral feedbacks such as learning that may take place through adaptive management of ecosystems." [26] Also at http://maweb.org/en/About.aspx.

Each one of these efforts and their integration provide a portfolio of methodologies for International Development projects at the implementation and assessment stage that points out to one important characteristic: the improvement of human wellbeing is embedded within a very complex and dynamic system that directly depends in the state of ecosystems and is highly affected by individual and collective decisions as well as human perceptions. A recent report highlights the importance of computational research to tackle this kind of complex problems [27]. Previous dynamic simulation studies have included a broad range of variables with an integrated framework that includes data related to various social, economic or the environmental aspects [28], [29]. More work with dynamic models of complex systems that include individual and collective interactions and decision making processes will be crucial to expand the scope of the work on human wellbeing and electric energy consumption. Such work needs to incorporate stakeholders at the community level, policy making, and scientific scholars in order to appropriately tackle the grand challenges ahead. Higher education institutions collaborating at international level are the ideal place to based the research efforts because of the potential to link national laboratories, local communities, private industry, governmental and non-governmental organizations.

CONCLUSION

This paper discussed the main concepts of a data-driven approach for finding relationships between energy consumption and well-being indices. The uncovered observations constitute first steps toward building a framework for sensible policy making that center around wellbeing and sustainability. During the summer of 2012 a brief guideline to Measure Wellbeing was published [22] by the new economics foundation (nef), and it could serve as a starting point for different kinds of organizations to initiate formal efforts to include subjective wellbeing measures in their assessment and evaluation plans. Data from different local initiatives could inform participatory processes and energy policy debates. A path towards sustainable wellbeing needs to become part of the vision of many different types of organizations in order to engage the public in a meaningful decision making process. Chambers provided an excellent concept described as responsible well-being more than a ten years ago in which the wellbeing of the wealthy are not sacrificed in benefit of the poorest communities; "*those with more wealth and power will not just accept having less, but will welcome it as a means to well-being, to a better quality of life*" [30]. In other words, if community wisdom is achieved, the wealthy will establish meaningful efforts to benefit the underserved communities, not necessarily out of kindness, but out of the conviction that to maximize their own personal wellbeing, a minimum level of cooperation and empathy needs to be achieved. The hope for a better future depends in our ability to become a wiser society making individual choices that strengthen the collective and facilitates individual wellbeing.

ACKNOWLEDGEMENT:
This work was supported in part by the National Science Foundation under Grant 103302, and by the National Endowment for the Humanities under Grant AC-50156-12.

REFERENCES:

[1] Practical Action (2012) Poor people's energy outlook 2012: Energy for earning a living, Practical Action Publishing, Rugby, UK. http://practicalaction.org/ppeo2012

[2] Fatih Birol, Abeeku Brew-Hammond, 2012. *Sustainable Energy for All: Technical Report of Task Force 1: in Support of the Objective to Achieve Universal Access to Modern Energy Services by 2030*, Task Force 1 of the UN Secretary-General's High-level Group, April 2012. http://www.sustainableenergyforall.org/

[3] A. D. Pasternak, *Global Energy Futures and Human Development: A Framework for Analysis*, Lawrence Livermore National Lab., U.S. Department of Energy, 2000. https://e-reports-ext.llnl.gov/pdf/239193.pdf

[4] J. Klugman, *2010 Human Development Report - The Real Wealth of Nations: Pathways to Human Development*, United Nations Development Program, page 66, 2010. http://hdr.undp.org/en/reports/global/hdr2010/.

[5] United Nations Development Programme, 2012. "Going beyond GDP, UNDP proposes human development measure of sustainability", Rio de Janeiro, Brazil, 20 June 2012. http://hdr.undp.org/en/mediacentre/press/.

[6] S. Abdallah, S. Mahony, N. Marks, J. Michaelson, C. Seaford, and S. Thompson, *Measuring Our Progress: The Power of Well-being*, New Economics Foundation, 2011. http://www.neweconomics.org/publications/measuring-our-progress.

[7] S. Abdallah, J. Michaelson, S. Shah, L. Stoll and N. Marks, *The Happy Planet Index: 2012 Report: A global index of sustainable well-being*, New Economics Foundation, 2012. http://www.happyplanetindex.org/.

[8] P. Dasgupta, *Human Well-Being and the Natural Environment*, Oxford University Press, 2004.

[9] Millennium Ecosystem Assessment, accessed July 2012, available at - http://maweb.org.

[10] Millennium Ecosystem Assessment Board, 2005. *Living Beyond Our Means: Natural Assets and Human Well-being*. Washington, DC. http://maweb.org/en/BoardStatement.aspx.

[11] Spierre, S.G.; Seager, T.; Selinger, E.; , "Determining an equitable allocation Of global carbon dioxide emissions," *IEEE International Symposium on Sustainable Systems and Technology (ISSST)*, pp.1-5, 2010.

[12] J. Stiglitz, A. Sen, J. Fitoussi, “Report by the commission of the measurement of economic performance and social progress”, *CMEPSP, September, 14,* 2009. http://www.stiglitz-sen-fitoussi.fr/en/documents.htm
[13] Thring M. W. Thring, *The engineers conscience*. Ispwhich Book Co, 1980.
[14] M. Castro-Sitiriche, Papadopoulos, Christopher; Frey, William; Huyke, Hector; , "Sustainable Wellbeing Education in Engineering," *Sustainable Systems and Technology (ISSST), 2012 IEEE International Symposium on* , vol., no., pp.1-6, 16-18 May 2012.
[15] R. Layard, "Why subjective well-being should be the measure of progress", OECD World Forum on “Statistics, Knowledge and Policy - Charting Progress, Building Visions, Improving Life", Busan, Korea 27-30 October 2009.
[16] Helliwell, J., Layard, R., and Sachs, J., *World Happiness Report,* New York: Earth Institute, Columbia University, 2012. http://earth.columbia.edu/articles/view/2960
[17] H, Héctor, *Tras otro progreso: Filosofía de la tecnología como si las cercanías importaran*, 2012.
[18] Costanza, Robert, *et al.*,**(**2008) “An Integrative Approach to Quality of Life Measurement, Research, and Policy », *S.A.P.I.EN.S*, 1.1 | 2008. Available: http://sapiens.revues.org/169.
[19] J. Alameda, I. Díaz, *Index of Sustainable and Ecoconomic Welfare for Puerto Rico*, Instituto Tropical de Energía, Ambiente (ITEAS), UPRM, Mayagüez, Puerto Rico, 2011.
[20] Sen, A. *Development as Freedom*, Anchor, 2000.
[21] Abdallah, S. Thompson, J. Michaelson, N. Marks, and N. Steuer, *The Happy Planet Index 2.0,* New Economics Foundation, 2009. Available at - http://www.happyplanetindex.org/.
[22] J. Michaelson, S. Mahony, J. Schifferes, *Measuring Well-being*, New Economics Foundation, July 30, 2012. http://www.neweconomics.org/publications/measuring-well-being
[23] Mackay, D., *People, Power, Area - How the Laws of Physics Constrain Our Sustainable Energy Options,* 2012. http://www.inference.phy.cam.ac.uk/mackay/presentations/ted/mgp00040.html
[24] Mackay, D., *Sustainable Energy: Without the hot air*, 2009. http://www.inference.phy.cam.ac.uk/withouthotair/c18/page_112.shtml
[25] Max-Neef, M. “Economic growth and quality of life: a threshold hypothesis”, *Ecological Economics* **15,** 115–118, 1995.
[26] Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC, pages i, 1, 23. http://maweb.org/en/Synthesis.aspx
[27] National Research Council, 2012. *Computing Research for Sustainability*. Washington, DC: The National Academies Press, 2012. http://www.nap.edu/catalog.php?record_id=13415.
[28] A.M. Bassi, John P. Ansah, Zhuohua Tan, Matteo Pedercini, 2011. “Modelling global green investment scenarios: Supporting the transition to a global green economy”, Chapter in *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication,* UNEP, 2011. www.unep.org/greeneconomy
[29] A.M. Bassi, 2011. A context-inclusive approach to support energy policy formulation and evaluation”, *Regional Environmental Change*. 2011; 11(2):285-295. http://www.springerlink.com/content/qj26643337022732/.
[30] Chambers, R. 1997. Editorial: Responsible well-being – a personal agenda for development. World Development 25: 1743–1754. http://css.escwa.org.lb/sd/1382/lecture1_Chambers.pdf.