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Natural Resources, Renewable Energy Sources, GHG-emission and Demographic Profiles in United States: A Broad Analysis for Developing Sustainable Low-Carbon Energy Sector

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Abstract

Renewable energy production is a priority policy agenda in US. The natural and renewable energy resource availability, energy use trends and demographic profiles are all critical components for correctly gearing the proper and sustainable development of this sector. Co-assessment of the natural and renewable energy resources in US *is a must* for renewable energy industry growth without dramatic environmental detrimental effects. For analyzing the natural and renewable energy resources and its developmental potential, this concept paper divides US into seven different regions (*R-1: Northeast; R-2: Southeast; R-3: Midwest; R-4: Southcentral; R-5: Northwest; R-6: Southwest; R-7: Alaska & Hawaii*). Based on parameters such as land availability, water resource availability, demographic patterns, and renewable energy sources, natural resource index (NRI), renewable energy index (REI) and development potential index (DPI) were defined and calculated for these various regions. Our analysis showed that R-6 had high NRI (6) and REI (14). Therefore it had the highest DPI (20). There were also marked differences in various regions with respect to energy use and GHG-emissions. The R-3, R-4 and R-5 regions had high-energy use and GHG-emissions. In light of these broader trends, the implications and the need for regional prioritization, resource coupling, investment allocation, and future policy directions for optimal and sustainable renewable energy production were discussed.

Key words: Bioenergy; Renewable energy; Low-carbon energy; US Energy Policy

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INTRODUCTION

Low-carbon renewable energy production is going to be major driver in the direction of sustainability. Generating electricity, heat or biofuels from renewable energy sources has become a high priority in the energy policy strategies at global and national levels (Arent, *et al.,* 2011; Jacobson, 2009; Resch *et al.,* 2008). Recently two exciting reports on 100% renewable energy-powered-planet were published and both of these visions are particularly important especially in the light of the fact that the energy industry, investments and technology landscape in many countries are taking a major shift towards renewable energy (Jacobson & Delucchi, 2011a,b; WWF, 2011). Although extremely ambitious, a world powered exclusively by renewable energy sources is a dream and realistically a prime necessity for the sustainable future of our planet. Due to its large requirements for space and the need for a rapid development of new renewable projects in the face of climate change and the peak oil debate, renewable energy sector may become one of the most important drivers of global environmental and social change in the future.

The notion of renewable energy production becomes particularly important for US because of several key reasons: 1) The US is the second largest consumer of energy and energy consumption has increased at a faster rate than energy production over the last fifty years in the

US. This difference is now largely met through imports. With expanding economy, growing population, and rising standard of living, demand for all types of energy is expected to increase by 31% within 25 years (National Energy Policy Report, 2001); 2) Unlike other developed nations such as Germany, US heavily rely on fossil-based energy sources (an estimated 90%); 3) US is the second largest emitter of greenhouse gas (GHG) emission, and an estimated 85% of that comes from fossil-fuel burning. Global nations are increasingly geared towards GHG-reduction via global binding agreements to obviate climate-change mediated planetary effects. Further, US economy has to be shifted to low-carbon energy sources to remain competent in many markets; 4) Geo-political reasons such as increased political stir in Middle East nations and growing tension between Iran is a major issue for future oil trade; 5) Resource reasons such as depleting world reserves, rising oil prices and increasing demand from prolifically growing countries such as China and India. The EIA expects that India and China to use 12 million barrels a day by 2015, which will be more than one-fifth of the global demand (EIA, 2012).

Realizing these trends, energy security ranks as a top agenda in US politics and has long been a subject of continues worry among US politicians. The establishment of energy sustainability and innovation as the current US administration's top priority has only further increased the attention given to these issues (PCAST, 2010). Still sadly, the changes in domestic energy policy directed to tackle energy independence over the last decades were incremental (Morrow et al., 2010). Although there are numerous policy initiatives, debates and discussion on a national energy policy (National Energy Policy Report, 2001), the US still lacks a solid policy foundation to meet these growing energy challenges. The Energy Policy Act of 2005, the Energy Independence and Security Act of 2007 and the Food, Conservation, and Energy Act of 2008 are the main laws that address some of the energy technology challenges in the US and in that the EISA consists mainly of provisions to design to increase energy efficiency and the availability of renewable energy.

Governmental policies, legislations, strategies and regulations are the major factors in providing favorable environment for the development of renewable energy resources especially those technologies, which requires risky and large initial investments. With a political mood for a national energy policy, many policy planners are conceiving and drafting bills with the key mission of an integrated and strategic approach to clean-energy innovation, production, efficiency, and deployment. However, a major challenge faced by policy makers is to come up with a renewable energy plan without upsetting the traditional energy industries and still have a nation-wide effect. This notion brings to the main discussion area of this article.

Geographically, the US, which has 3.8 million square miles area and 300 million population (US Census Bureau, 2011), have a very diverse array of climatic regions, land availability, soil characteristics, water resources and agriculture practices in the various regions. With respect to renewable energy production this diversity is a both a blessing and a potential problem. Understanding this diversity is a very vital exercise for any major nation-wide policy initiative. A national agenda to diffuse renewable energy production including bioenergy production on a much larger scale brings enormous challenges to implement various programmatic goals as part of single federal energy policy legislation. The natural resource and renewable energy resource availability, the current investment trends and demographic profiles are all critical components for properly gearing the sustainable development of this sector. The major objective of this article is to broadly delineate the diversity in natural resources, renewable energy resources and demographic profile of continental US by dividing the land into various regions of similar features. Then the paper tries to correlate the interplay among these major indicators and discuss some of the future directions in light of some of the broader trends from these various regions.

1. FOSSIL FUEL TO RENEWABLE ENERGY: A MAJOR PARADIGM SHIFT FOR US ENERGY LANDSCAPE

As mentioned earlier, for facilitating the clean-energy production, several legislative mandates for renewable energy research and production are underway in US (Taylor, 2008; Verbruggen *et al.,* 2010). The effort to meet these needs for new energy sources should take care not to sacrifice other critical natural resources. Unsustainable production schemes for new energy production could also lead to irreversible consequences in natural resources; therefore, intensive research and modeling must be conducted to investigate and predict the effect of new generation energy systems on natural resources. An energy transition in the US away from fossil fuel to low carbon renewable energy based system would be very expensive, both economically and politically (Victor, 2004). Further, this transition is going to be a major paradigm shift in many respects. There needs to be bipartisan political will and credible 'disruptive energy policies' with a focus on renewable energy and climate change to support such a transition. Further, operation of larger commercial renewable energy production needs development of many disruptive technologies, innovative design and deployment strategies. There are many practical challenges associated with large-scale deployment of renewable energy production. Renewable energy technologies are often recognized as less competitive than traditional electric energy conversion systems. Obstacles with renewable electric energy conversion systems are often referred to the intermittency of the energy sources and the relatively high initial capital cost (Skoglund *et al.,* 2010). Moreover, renewable energy production systems can be highly resource-intensive and requires larger natural resource footprint because of the less-dense energy content nature of new generation energy systems compared to energy dense fossil fuels (Subhadra, 2011a).

Identifying resources and a precise estimation of areas for renewable energy sector for future development with a focus on natural resource (land and water), renewable energy resource and US demographic profiles, therefore, play an important role in energy policy planning. Renewable energy and natural resource mapping and aligning energy production in areas with large energy consumption in US are some of the key areas. A highly optimized energy production, distribution, and consumption via newly proposed smart grids (Jacobson & Delucchi, 2011b; Subhadra, 2010a; Subhadra & Edwards, 2010) are also major steps for reducing the energy loss and thereby, increase the overall energy efficiency. This is particularly important in the case of liquid fuel production from biomass because of several reasons. The petroleum based feedstock processing and production is aggregated in small industrial area where bulk processing occurs. The high-energy content nature of the petroleum fuel still has a lot of positive energy to end consumers; therefore large scale and longer distribution channels are viable from a positive energy standpoint. However, bio-based fuels are less-energy dense materials and large-scale moving of high-volume feedstock requires a lot of energy, which obviates the positive benefits of biofuel mandates with respect to being climate and environment friendly. Hence, ideally both the feedstock as well as the processed fuel has to be used without substantial distributional energy loss and cost. So we need to have a basic idea about where energy consumption are more, and which regions we need to focus to develop for renewable energy and bioenergy production and distribution (Willems, 2009).

2. DIVIDING US INTO SEVEN GEOGRAPHICAL AREAS FOR A DISCUSSION ON NATURAL RESOURCE AND RENEWABLE RESOURCE AVAILABILITY

For analyzing the resource potential, this paper divides US into seven regions (R):

R-1: Northeast; R-2: Southeast; R-3: Midwest; R-4: Southcentral; R-5: Northwest

R-6: Southwest; R-7: Alaska & Hawaii

Figure 1 shows a diagrammatic representation of these different regions in US. Although, the basis of this division is empirical, there are certain salient and unifying features with respect to climatic conditions and resource nature among the individual states in each region.

Figure 1
The Continental US Divided into Seven Regions for Assessing Natural Resource and Renewable Energy Resource

For example, most of the Southwest region (R-6), which comprises of five States, has similar climatic conditions (semiarid steppe and mid-latitude desert climate) and precipitation levels and similar resources with respect to land, water and renewable energy sources. Further, these regions also share common issues with respect to resource issues such as water scarcity (Subhadra, 2010b; Subhadra, 2011b). R-1 comprises of thirteen Northeast states and is the region with highest population density of 349 per square mile (PSM). The 5 states in the Southeast comprise R-2 with a moderate population density. The 13 traditional Midwest agricultural states comprise of R-3 and have low to moderate population density. The 5 states in the Southcentral and 6 states in the Southwest comprise of R- 4 and R-6, respectively and have low population densities. The 5 Northwest states make R-5 and also had a low population density. R-7 comprised of Alaska and Hawaii and disproportionally very large un-used area of Alaska make the comparison of this region to other regions difficult, however for the sake of the resource information it is included as a separate region. In the subsequent section, I discuss some of the natural resource features of these various regions.

3. LAND AND WATER: TWO KEY NATURAL RESOURCE FOR FUTURE RENEWABLE ENERGY SECTOR

Land and water are major resources for sustainable development for any society (Hoekstral & Mekonnen, 2012; Vörösmarty, *et al.,* 2005). Competing needs for land-use is a major sustainability challenge globally and this issue becomes more serious with respect to energy production (Searchinger *et al.,* 2008). Vast stretches of land are required for renewable energy production whether it is solar, wind or biomass. Wind and solar energies are infinite from a resource standpoint; however, the available land from which to harvest them is finite. Similarly, the land required to grow any biomass feedstock for biofuel to meet a large demand is also finite (Subhadra, 2011a). Thus, the primary constraint in future energy scenarios is not energy sources as such but rather the land and water required to harvest or grow or process them. This constraint on natural resources becomes particularly important in the wake of another global challenge. There is greater need for more agricultural land for providing 'dietary energy' for the planet's growing population (Godfray *et al.,* 2010; Sachs *et al.,* 2010). However, the productive agricultural land on our planet is decreasing due to extreme climate and unpredicted weather attributed mainly to increasing greenhouse gas (GHG)-emissions (IFPRI, 2009). Moreover, the agricultural lands which are already in use might need more natural resources such as irrigation water for the same level of production which brings additional constraints on available water resources. Similarly, water - another finite natural resource - consumption represents a major challenge for future energy production (Gerbens-Leenes *et al.,* 2009; Subhadra, 2010b, c; Subhadra & Edwards, 2011b). This complex nexus of Energy-Water-Food nexus is major natural resource management issue in dietary as well as other energy production.

The Energy-Water nexus treats energy and water as being intertwined primarily in terms of resource use. Energy is required to secure, deliver, treat, and distribute water (Bhardwaj, 2011). Similarly, water is used, consumed, and often degraded to develop, process, and deliver energy for consumption (Scott *et al.,* 2011). Concern over production and consumption of coupled energy and water use stems principally from the operational focus of water and power utility companies. Because of the emphasis on resource consumption, the nexus is often characterized in resource use efficiency terms, e.g., cubic meters of water needed to generate a kilowatt-hour of electrical power or, conversely, kilowatt-hours of electricity consumed per cubic meter of water supplied. The input-output understanding of energy and water inter-linkages is mirrored by footprint calculators - defined as metrics of the carbon, energy, or water consumption of human activities (Gerbens-Leenes *et al.,* 2009). It seems likely that the net outcome of treating the three areas of the Energy-Water-Food nexus holistically would lead to a more optimal allocation of resources, improved economic efficiency, lower environmental and health impacts and better economic development conditions, in short, overall optimization of welfare. The approach to the energy, water, and food nexus normally depends on the perspective of the policy-maker (Harris, 2002). If a water perspective is adopted, then food and energy systems are users of the resource; from a food perspective energy and water are inputs and; from an energy perspective, water as well as bio-resources (e.g., biomass in form of energy crops) are generally an input or resource requirement and food is generally the output. Food and water supply as well as wastewater treatment require significant amounts of energy. Of course, areas such as food-as-fuels (i.e., biofuels) tend to even complicate these descriptions due to additional impacts associated with land use, land use change and use of the available biomass resource. Mutual energy and water interactions present local to global resource tradeoffs at a range of scales and with critical, multi-tiered institutional and decision-making complexities (Scott *et al.,* 2011).

With respect to land and water resources, the different regions in US have marked difference and the land resource index (LRI) and water resource index (WRI). As shown in table 1, R-1 has low LRI because of less land area, high population density and high level of urbanization. This suggests that larger renewable energy projects (e.g. very large wind farms, large acreage of energy crops etc.), which requires substantial land footprint, might not be very feasible for this region. However, because of high WRI (i.e. availability of significant amount of water resources and water surface areas) this region can be well suited for indoor-based high algal biomass turnover technologies. There is moderate level land availability in R-2 for large-scale energy crops such as energy grass and other potential energy crops. This region has also substantial potential for pond-based algal biofuel production schemes. Algal biofuel is a water intensive sector, and ideally this should be located to areas with large sources of water resources. Already, companies such as Algenol are developing algal-based biorefineries in this region.

R-3, is the agriculture heartland in US, has reported to have substantial production of major agri-crops, both energy as well as food crops. Although the LRI is high, the land area is already substantially utilized for agriculture and other agro-industrial sectors. However, there is still potential for energy-grass based agriculture crop in this region because of the agriculture tradition and farming infrastructure technologies that can fast sweep and diffuse into practice in relatively low time frame. Careful initiatives should be taken to safeguard food crops as energy markets are much larger there is a risk of fuel crops taking over food crops (Subhadra & Grinson-George, 2011). R-4, R-5 and R-6 have good LRI and have a lot of un-used land, which can be very productively channeled for large-scale renewable energy production, which requires significant land footprint. However, the R-5 and R-6 has low LRI, which can be a significant problem for bioenergy production. Energy crops and technologies which uses less water for growing such as *Agave spp.* (Sommerville et al., 2010) and hybrid strains of energy grass couple with high water recycling schemes might be required for this region. Because of the optimal sunlight, temperature and relatively high growing seasons algae-based biofuel industry can be major driver for economic activity in R-6, especially in semi-arid unused lands in New Mexico and Arizona (Pate *et al.,* 2011; Subhadra & Edwards, 2010, 2011). Again, tight policies and regulations for water use should be integrated into the developmental schemes (Subhadra, 2011b). R-7 (Alaska and Hawaii) have very high LRI and WRI and may be ideally be utilized for local energy low carbon energy production both renewable electricity and liquid biofuel.

4. RENEWABLE ENERGY RESOURCE POTENTIAL OF VARIOUS REGIONS IN US (TABLE 1)

Presently wind energy is the fastest growing renewable energy resource having global installed capacity of 121 GW (GWEC, 2010) and during the last decade there has been an average annual growth rate of 30% for the installed wind energy. Similar to this global trend, there was an exponential growth in installed wind energy capacity in US from 2000 to 2011 (AWEA, 2011). Wind energy technology is quite mature and the installed utility scale wind power capacity, through 4th quarter of 2011 in the US is 41,400 MW (AWEA, 2011). Furthermore, the US has implemented a federal law aimed at generating 20% of domestic electricity demand by wind by 2030 (AWEA, 2008). The US Department of Energy (DOE) estimated that 300 GW must be installed by 2030 to achieve this goal and that this will cover an overall inland area of 15 million acres. Presently, wind energy is the second cheapest source to produce power, in the coming years with the expansion of distributive networks, and other technological improvements would bring wind energy at par with fossil fuels. It will also significantly minimize the emission of GHG; thereby provide a greener environment and a stable energy resource. However, there are some negative effects due to large wind farms; they cast shadows, create noise, can obstruct a view and potentially disrupt the local wildlife and fauna (Daim *et al.,* 2009). Hence, future wind farms may be ideally suited for regions with high potential semi-arid barren lands and in places with low population density and biodiversity.

With respect to wind energy, R-1 has relatively low to moderate resource but have almost 3200 MW of installed capacity. R-3 has relatively good wind energy potential and the region has the highest installed capacity in the US. Region 4 has very good potential and has utilized this resource optimally. However, Texas has almost 90% of the installed capacity in this region and other states in the region can also be optimally exploiting the wind resources. R-5 and R-6 have excellent untapped potential and can be optimally utilized for the expansion of wind energy production.

Technically, solar energy has resource potential that far exceeds the entire global energy demand. Even when evaluated on a regional basis, the technical potential of solar energy in most regions of the world is many times greater than current total primary energy consumption in those regions (Timilsina *et al.,* 2012). Despite this technical potential and the recent exponential growth of the market, the contribution of solar energy to the US energy supply mix is still negligible. The policy landscape for solar energy is complex with a broad range of policy instruments driving market growth. The rapid market growth of solar energy in Germany and Spain could be attributed to the feed-in-tariff (FIT) systems that guarantee attractive returns on investment along with the regulatory requirements mandating 100% grid access and power purchase. On the other hand, federal and state incentives, along with regulatory mechanisms such as RPS, get credit for the rapid deployment of solar energy in the United States. In both markets, the policy landscape is in a transitional phase. In Germany, the FIT level is being reduced, whereas in the United States, upfront incentives are being shifted toward performance-based incentives.

Table 1
Population Trends, Natural Resource and Renewable Energy Potential for Different Regions in United States

Region	States in the Region	Population[1] (millions)	Total Land Area (million sq. miles, (MSM))	Water Area (% of land area)	Population Density (per land sq. miles, PSM)	LRI[2]	WRI[3]	NRI[4]	Solar[5]	Wind[5]	Geo[5]	Biomass[6] (million metric tons, (MMT))	REI[7]	DPI[8]
R1	CT, ME, MA, NH, RI, VT, NJ, NY, DE, MD, PE, VA, WV	72.0	0.26	10	349	+	+++	***4***	+	++	+	+++ *(34)*	***7***	***11***
R2	AL, FL, GA, NC, SC	52.6	0.26	21	287	++	++++	***6***	+	+	+	+++ *(54)*	***6***	***12***

To be continued

Continued

Region	States in the Region	Population[1] (millions)	Total Land Area (million sq. miles, (MSM))	Water Area (% of land area)	Population Density (per land sq. miles, PSM)	LRI [2]	WRI[3]	NRI[4]	Solar [5]	Wind [5]	Geo[5]	Biomass[6] (million metric tons, (MMT))	REI[7]	DPI[8]
R3	KE, IL, IN, MI, MN, OH, WI, IA, KS, MO, NE, ND, SD	71.3	0.85	12	98	+++++	+++	***8***	+	++	+	+++++ *(217)*	***9***	***17***
R4	AR, TX, TN, LO, MS, OK	45.7	0.53	4	88	++++	+	***5***	++	+++	++	+++ *(66)*	***10***	***15***
R5	MT, ID, WY, WA, OR	12.7	0.50	2	26	++++	+	***5***	++	+++	+++	+++ *(27)*	***10***	***15***
R6	UT, CO, AR, CA, NM, NV	56.2	0.70	2.5	82	+++++	+	***6***	++++	+++	++++	+++ *(19)*	***14***	20
R7	AK and HI	2.1	0.68	14	4	+++++	+++	***8***	-	+	-	+ *(1)*	***2***	***10***

Note:
[1] Compiled from US. Census Bureau data, 2011
[2] LRI= land resource index derived as follows, + = fair (100-300 MSM & 200-400 PSM); ++ = good (100-300 MSM & 100-300 PSM); +++ = very good (100-300 MSM & < 100PSM); ++++ = excellent (300-400 MSM & < 100PSM); +++++ = extraordinarily high (300-400 MSM & < 100PSM)
[3] WRI= water resource index derived as follows, + = fair (water area 1-4% of land area); ++ = good (4-8%); +++ = very good (8-16%); ++++ = excellent (16-25%)
[4] NRI = Natural Resource Index derived as the additive of LRI + WRI
[5] += fair; ++ = good; +++ = very good; ++++ = excellent. The index were derived and compiled according to the solar, wind and geothermal maps renewable energy map from NREL (Subhadra and Edwards, 2010),
[6] The data were compiled from the biomass resource data from Milbrandt (2005) and the index were derived as follows, + fair = less than 20 MMT; ++ good =20-50MMT; +++ very good =50-100MMT; ++++ excellent = 100-200MMT; +++++ extraordinarily high = greater than 200MMT
[7] REI = renewable energy index derived as the additive of solar + wind +geothermal+ biomass
[8] DPI= developmental potential index derived as the additive of NRI + REI

Table 2
Salient Characteristics of Different Regions with Respect to Installed Wind, Solar and Advanced Biorefineries and Energy Use

Region	DPI	Total Installed Wind Energy (MW)[1]	Total Installed Grid connected PV Energy (MW) [1]	# of Biorefineries[3]	Investment (in Millions) [3]	Average Per Capita Energy Consumption (Million Btu) [4]	Per Capita Energy Transportation Consumption Efficiency[5]	GHG emission Intensity[6] (tCO_2 e/$million of GSP)
R1	11	3156	463	2	52	269	+	677
R2	12	0	116	3	75	311	+	651
R3	17	14970	59	10	519	382	+++	1089
R4	15	11864	41	4	207	450	+++	1155
R5	15	6930	37	3	79	458	++	1412
R6	20	6612	1403	4	118	231	+	712
R7	10	73	48	1	25	559	+	1106

Note:
[1]Data as of 09/2011, NREL, DOE, Wind Powering America US Installed Wind Power; (NREL, 2011)
[2] Data as of 2011 Sherwood. L., US Solar Market Trends 2010, June 2011, Inter State Renewable Energy Council
[3] Data from US DOE web portal, Energy Efficiency and Renewable Energy, Biomass Program information
[4] Data from US Energy Information Administration, State Energy Data 2009; Consumption. The value represents the average of the various States Average Per capita Energy consumption in the specific region
[5] Data from US Energy Information Administration, State Energy Data 2009; Consumption. The index is an empirical value based on the various States Average Per capita Energy transportation consumption in the specific region
[6] Data from Ramseur (2007); CRS report for Congress. The value represents the average of the various States GHG emission intensity calculated as tons of CO_2 equivalent per million of Gross State Product (tCO_2 e/$million of GSP) in the specific region

R-1 has low solar potential; however, has one of the largest PV grid-connected installed energy in US. Again this suggests the role of state policies in spurring the diffusion and adoption of technology. Regions with good solar energy potentials such as R-4 and R-5 have not tapped this energy resource and have low installed capacity. R-6 has the highest potential for solar energy, and has the highest installed capacity in US with California contributes almost 80-90% of this installed capacity. This is primarily due to the California State polices such as low-carbon fuel standard regulation.

Biomass-based energy production is also slowly picking up in US, especially from advanced feedstocks such as dedicated energy crops (energy grass), agriculture residues, algal biomass, industrial wastes and forest residues. Table1 shows the potential for each region. With regards to biomass, R-3 has the exceptionally high potential mainly due the availability of feedstocks such as agriculture resides, forest residues and dedicated energy crops. R-4 and R-5 also has good biomass potential. Geothermal energy resource is sparsely is a relatively new renewable energy generating system and some regions in US are uniquely positioned to co-develop this with other energy production schemes.

Table 1 also shows that the certain regions have concentrated sources of multiple renewable energies such as solar, wind, and geothermal. Land areas with no competing interest and with availability of ample renewable sources energy are identified to create renewable energy corridors (Subhadra, 2010a). As these regions possess multiple energy sources, they are highly suitable for consideration as ''Integrated Renewable Energy Parks'' (IREPs). The IREPs deployed in these corridors can then simultaneously and synergistically produce solar, wind or geothermal energy for developing a smart grid for green electricity production (Subhadra, 2010a; Subhadra & Edwards, 2010). These are integrated macro-level energy production model for sustainable production of renewable energy with less environmental (land and water) footprint (Subhadra & Edwards, 2010). IREPs complement and optimize integrated energy production process with no or minimal fossil fuel input creating environmental-friendly, emission-free energy parks. Advanced biofuel feedstocks such as algae, forest residues and switch grass are getting increasing attention as sustainable feedstocks for biofuel production. Algal growth and processing facilities and lignocellulose-based biorefineries can be co-deployed in IREP framework for production of liquid fuel.

5. PER CAPITA ENERGY USE AND GHG-EMISSION IN VARIOUS REGIONS OF US

The United States is the 2nd largest energy consumer in terms of total use in 2010 and industrial and transportation sectors are the two major consumers of energy. Table 2 show the per capita total energy consumption, per capita transportation energy consumption and GHG emission of the various regions. R-1 and R-6 has the lowest energy per capita use, whereas R-2 has moderate energy per capital use. The regions R-3, R-4, and R-5 have high average per capita energy and transportation consumptions (Table 2). The GHG-emission intensity of these various regions clearly aligned with energy use; i.e. high GHG-emission in regions with high energy uses and vice versa. This high-energy use in these regions can be particularly attributed to high agricultural and industrial energy use in these regions. The information about energy use in each region is going to play a major role in developing optimum production areas for future energy production.

6. CORRELATING THE NATURAL RESOURCE AND RENEWABLE ENERGY RESOURCE FOR DEVELOPMENTAL POTENTIAL: POLICY OPTIONS

There are some major trends, which can be deduced from the broad analysis on the regions. With respect to developmental potential, the R-6 region has the highest DPI (20) and is poised to be the best for renewable energy production including advanced biomass production to meet the growing energy demand of future. R-4 and R-5 also has good DPI (15) and untapped natural as well as renewable energy resources. Even though R-3 has good DPI, safe policies and regulations should be envisioned for developmental potential of renewable energy from R-3. Policies for sustaining agricultural lands dedicated for food production should be enforced. Focus should be given to this area for agriculture byproduct-based (e.g. residues) biofuel production and also co-deploying wind energy production in agriculture farm lands. Already federal investments and biorefineries are sprawling in this region compared to other regions (Table 2). The energy use is high for certain regions and production and distribution potential of regions has to be optimized for meeting the growing energy demand in these regions. The regions with high potential might not be the regions with high-energy use, so definitely excess production has to grid connected to distribute to regions with high-energy use. Other demographic trends should also be taken into account in planning processes. For example, the states in R-6 include some of the states with the highest population growth rates. The US census bureau has projected that an additional 10-13 million people will reside in these regions by 2030 (Subhadra, 2011b). The greater population and the resulting increase in regional economic activity will increase the need for energy and water for civic and other industrial purposes. Future biofuel development and infrastructure constraints in various regions are also a major factor to consider in energy planning processes. There arise numerous questions with respect to investment, policy and developmental agenda for low carbon energy sector in US: *whether the natural resource availability in each region would support a renewable energy potential that region? Whether major infrastructure needs are required for some regions? Whether there should be more focus towards certain regions? Is there a need for novel distribution or energy consumption strategies for different regions?* The broad analysis from this paper based on some of the described indices brings some interesting insights and future directions:

6.1 Key Federal Low-Carbon Renewable Energy Policies

Energy-based economic development (EBED) studies describe the positive close-relationship between energy policy planning and economic development (Carley *et al.,* 2011) and there is no other sector than energy sector, which can directly impact the gross productivity of any nation. US legislatures and leaders should realize this and act on the strategic importance of future low-carbon energy production and consumption. In US energy politics, finding a majority to change the status quo more than incremental ways has been difficult and few have suggested the possibility of placing climate change and energy security on the decision making agenda at the same time has to overcome some of these hurdles (Bang, 2010). Bipartisan legislative initiatives at least in energy and climate sector should be a priority and federal energy policies aimed at the larger diffusion of renewable energy production should be a vital area of focus for US legislature. How key national policies can drive renewable energy sector in different paths can be elucidated from comparing US and Germany federal energy policies (Laird & Stefes, 2009). The United States and Germany started out with very similar policies for renewable energy after the energy crisis of the 1970s. By the year 2000 they were on very different policy paths and, as a result, the German renewable energy industry has moved well ahead of that in the United States, both in terms of installed capacity in the country and in terms of creating a highly successful export market Independent analysis of the historical path-dependent dynamics of each country suggests that those who wish to further renewable energy policy in the United States need to take into account these institutional and social factors so that they will better be able to exploit the next set of favorable historical circumstances (Laird & Stefes, 2009). It is not just federal policies but policies coupled with innovative strategies and new institutional frameworks will be highly necessary for US energy landscape. Recently, a policy memo from Harvard University recommended the improvement of the structure and management of energy technology and innovation at US institutions and described key principles for attaining such a restructuring (Anadon *et al.,* 2010). Other studies have also highlighted the urgent need to build a highly efficient organizational structure at a scale and speed that is sufficiently bold to address energy security and climate change, the two greatest challenges of the current times (Subhadra, 2012). Federal polices targeted towards the high potential region such as R-6 (Table 2) is the major first step for the low-carbon energy strategy.

6.2 Policy and Investment Initiatives from State Governments

As states in same region, share some unique features, the states should take initiatives for regional consortiums and investment forums, which will be a highly needed catalyst for the renewable energy developmental activities. Despite the hesitant pace of energy policy at the national level, state policies on renewable energy and climate change have been on the rise in the US, providing states with various options for encouraging the generation of renewable electricity (Peterson & Rose, 2006; Prasad & Munch, 2012). Most of these are focused around two different state renewable energy policies-Renewable Portfolio Standards and Mandatory Green Power Options-on installed renewable energy capacity. Studies have shown that both of these can very positively contribute to renewable energy sector (Delmas & Montes-Sancho, 2011). Another evaluation of state energy policies on decarbonization of US electricity sector suggests the synergistic effect of reducing the emissions when energy and climate change (e.g. carbon price) polices are integrated (Carley, 2011).

There are some striking policy indicatives from certain states, which highly facilitated higher rate of renewable energy production. For example, the exponential growth rate of wind energy and installed capacity in Texas can be attributed to the fact that Texas, which is in R-4, was one of the first states in the nation to enact a Renewable Portfolio Standard (RPS), and it did so in an innovative manner that set the state apart. The RPS was established in 1999 as part of the Texas Legislature's comprehensive restructuring of the electric industry in Texas (Diffen, 2009). However, other states in the region such as Oklahoma, Louisiana and Arkansas has also got good to moderate potential for wind energy which can be optimally utilized for regional energy demands.

Similar is the case of solar energy growth in California (R-6). In 2007, California launched its 10-year, \$3 billion '*Go Solar California'* campaign. The largest part of this campaign is the California Solar Initiative (CSI), overseen by the California Public Utilities Commission (CPUC). The CSI awards rebates and performance-based incentives for customers serviced by the state's major investor-owned electric utilities. With \$227 million in CSI incentives, over 175 MW of PV was installed in 2010 through this program. In addition, California has an RPS requirement of 20% by 2013 and 33% by 2020. This includes all renewable technologies and led to 90 MW of utility sector photovoltaic installations in 2010. Some 58 MW of these installations were in Nevada with the electricity produced flowing to California. The RPS requirement will lead to more utility-sector solar installations in future years. In New Jersey, an RPS with a solar requirement built a strong PV market. The solar requirement is 306 GWh in 2011 increasing to 5,316 GWh in 2026 (Sherwood, 2010). States in R-6, especially New Mexico, Arizona, and Nevada have exceptionally high potential for solar energy production and state leadership should take legislative steps for the wise utilization of this yet untapped clean energy source.

States such as Minnesota is encouraging novel policy initiatives to encourage 'community wind projects' financed using a flip or revenue participation model (called Community-Based Energy Development (C-BED)). A community wind project is a wind power facility that is developed by local landowners with the goal of returning financial benefits to landowners beyond the typical lease payments and also by taking a greater role in the early development of projects. Minnesota is a leader in community based wind projects with more than 900 MW of wind projects completed (Yarano, 2008). These examples suggest the role of state initiatives and policies to make significant change in the energy production landscape. Other states should also take initiatives to support renewable energy production based on their resource potential. State and inter-state energy policies and leveraging collective resource force of various states and optimum policy for integration of renewable energy sources into the power generation system are fundamental for tackling regional energy challenges (Miah *et al.,* 2012).

6.3 Prioritizing Certain Regions with High Production Potential

As some regions are very optimally placed with respect to developmental potential (e.g. R-6), policies -both federal and state- focus for the optimum utilization of these untapped resources might spur a rapid development of low-carbon energy sector not just for this region but also for the whole nation.

6.4 New Infrastructure Requirements

Some regions with high wind energy potential are not well connected to grid. Similarly, an antiquated and inadequate transmission grid prevents us from routing electricity over long distances and thereby avoiding regional blackouts, such as California's. A smart grid development initiative with a focus on resource-rich area is needed to make optimum use of the resources. Further, highly planned distribution and grid management schemes with a focus on issues related with intermittency of renewable energy sources, variations in regional energy consumption and production should also be a key area (Jacobson & Delucchi, 2011b). Transportation infrastructure, both road and rail, with respect to a focus on regional energy production potential should be well accounted for in the infrastructure studies. Growing lignocellulosic bioenergy will require major changes in supply chain infrastructure and transport volumes will likely to exceed the combined capacity of current agricultural and energy supply chains, including grain, petroleum, and coal. Efficient supply chains can be achieved through decentralized conversion processes that facilitate local sourcing, satellite preprocessing and densification for long-distance transport, and business models (Richard, 2010). Integrated systems that are cost-effective and energy-efficient will require new ways of thinking about agriculture, energy infrastructure, and rural economic development. Implementing these integrated systems will require innovation and investment in novel technologies, efficient value chains, and socioeconomic and policy frameworks (Richard, 2010).

6.5 Advanced Biofuel Developmental Process

The developmental and research agenda for advanced biofuel crops and biorefineries technologies should also be poised in regions with high potential for those feedstocks. Although research and technology investments for developing lignocellusic biofuel, policies to spur initial growth of this industry is lacking. With regards to cellulosic based dedicated energy crops, policy and viable incentive targeted towards land owners, farmers, and other agri-entrepreneurs are highly needed for the diffusion of widespread use of the technology (Jensen *et al.,* 2011). A new agri-energy extension schemes has to be integrated into the land grant University system to nurture this sector. Similarly, training work force via technical programs and certificate are also critical. Further, a biorefinery based integrated industrial production schemes for the production of food, fuel, and chemical should also be envisioned for achieving sustainability as well as economic benefits of bio-based economy (Subhadra, 2010a,b,d; Subhadra & Grinson-George, 2011)

6.6 Energy Consumption, Consumer Behavior of Adopting Biofuel, and Energy Efficiency

While there are ambitious government targets to increase the share of renewable energy in many countries, it is increasingly recognized that social acceptance may be a constraining factor in achieving this target. This is particularly apparent in the case of wind energy, which has become a subject of contested debates in several countries largely due to its visual impact on landscapes. Factors influencing socio-political and community acceptance are increasingly recognized as being important for understanding the apparent contradictions between general public support for renewable energy innovation and the difficult realization of specific projects (Wüstenhagen *et al.,* 2007). Active involvement of consumers is an integral component of progress towards sustainable energy that is currently lacking. A startling 6.7% of the power generated in the US is lost—either through transmission or by poorly optimized appliances, lights, and other devices (EIA, 2009). A recent study estimated that new biofuel initiatives will impact nearly 80,000 sq. miles of arable land without a substantial increase in energy efficiency, thus adversely affecting energy sprawl (McDonald *et al.,* 2009). Given these facts, as we ramp up efforts to meet energy challenges and break ground with a new wave of innovations, energy conservation is perhaps equally as important as energy production. Therefore, behavioral changes in the real stakeholders -the people- can help to recover a significant portion of the energy frittered away. The low level of biofuel policy knowledge among Midwestern residents reinforces the view that the public is under-informed about most policy issues (Delshad *et al.,* 2010). Also per capita total energy and transportation energy use is high for certain region such as R-3, R-4 and R-5, so households, industrial units and agriculture producers in these regions should be targeted for energy efficiency extension services. Particular interest should be focused on energy efficient farming and industrial production.

Currently, virtually no research is underway on narrative arguments linking biofuels to ideals like civic duty, economic security, or environmental protection. As legislation and massive research efforts are underway, parallel measures designed to engage the public in these developmental processes are needed. Investment in scalable behavioral interventions may prove highly valuable in improving energy efficiency (Allcott & Mullainathan, 2010). It is imperative for policy planners to devise strategies to educate and disseminate information to customers about energy efficiency and prospective incentives. This is by far a bigger challenge than energy production, as it calls for a fundamental shift in people's perception of energy, sustainable development, the need for clean energy, and above all, the benefit accrued to posterity. The media and scientific discourse could also be steered toward shaping public attitudes. Land-grant universities can make an important contribution in this regard as they would run through the entire nation as intellectual veins of applied research, extension services, and outreach programs. Also, the proposed energy grant universities could develop vibrant extension and outreach programs to build a rapport with the public. The energy extension services can act as an interface to inform about the public about need for clean energy production, general principles energy efficiency, new energy-efficient products, new technology innovations, and also inform the public about the training and educational opportunities available in their region to take careers in this direction.

6.7 Sustainable Integrated Natural Resource Policies

As large quantities of multiple resources such as land, water and forest products are required for future energy production; the future resources policies for developmental agenda should have an integrated view. As discussed before, the complex nexus of Energy-Water-Food nexus treats energy, water and food production as being intertwined primarily in terms of resource use and one of the best ways to address this nexus is to have integrated modeling approach (Bazilian, 2011). Large-scale water use for renewable energy production, mainly biofuel production, might require novel water management policies, which has to be aligned with energy policies. Some of high potential regions such as R-6 have significant water resource issues. Even with recycling and conservation schemes, the some regions in R-6 (New Mexico and Arizona) may be faced with water problems in the future, and these will inhibit the sustainable growth of this energy sector. New policies and legislation for water sharing and permits among states should also be facilitated. Some of the older federal water sharing compacts governing water rights in these states may need to be revisited with provisions to incorporate current circumstance. Measures must be taken or considered for new infrastructure to move large scales of surface water from water-rich regions to water-short areas, a project analogous to the Chinese South-to-North Water Diversion Project, which is intended to funnel 45 billion cubic meters of water per year from the Yangtze River basin to the drier northern part of the country (Berkoff, 2003; Subhadra, 2011b). Other water management policies can be integrated with flood plain management. Sustainable floodplains via large-scale reconnection of river and river basin have numerous benefits; it helps in optimal water management, flood remediation and use of flood plains for flood-resistant biomass feedstock production (e.g. eel grass) (Opperman *et al.,* 2009). Other novel approaches such as underground water tunnels to move large scale volumes water from floodplains towards water scarce regions of interest such as R-6 might be a good infrastructure investment with respect to biofuel production (Pinter, 2005).

Similar infrastructure-based investments and long-term policies need to be developed to address water resource issues to enable the development of a sustainable algal biofuel sector in the region. Multiple federal water and energy agencies should develop an open access information and knowledge base that would contain data, tools, methods and models to facilitate the assessment of energy and water supplies, demands and linkages, as well as promote collaborative decision making at local and regional levels. Aggressive outreach and education States could play important roles in ensuring adequate water supplies for both civic and industrial uses of water. Many states develop water plans, which examine the water supply and demand situation and make provisions for helping local entities to cope with water shortages and plan for additional water supplies. Federal-state partnerships can be used in resolving difficult water allocation problems in water-short areas of the country. Forest based products are a major source of biomass feedstock for future lignocellulosic biofuel production. However, only sustainable utilization of forest products and residues should be allowed for biofuel production and safe polices to safeguard forest resources should also be part of future energy policies. Similarly, if marine resources were used for renewable energy production such as offshore wind and wave projects and marine algal biofuel production, significant integrated evaluation on the effects of these entities on the marine biological, physical and chemical parameters should be implemented. Safe policies and meaningful regulations for the optimum utilization of natural and renewable energy resources without any adverse environmental effects is the key for future widespread diffusion of energy technologies.

6.8 An Integrated Evaluation of Environmental Effects of Renewable Energy Systems

Energy markets are larger in size. Large-scale deployment of commercially viable technologies will happen in an exponential rate. Most of the effort so far has been directed to estimate the effect of renewable energy production is on life-cycle assessment with a focus on GHG-emissions. However, a comprehensive evaluation scheme need to consider other environmental impacts, which include effects on soil productivity, water quantity and quality, forest product sustainability, marine resources, biodiversity and ecosystem resilience, and wildlife habitat quality and quantity. Such an evaluation would also be applied to the production and use of all forms of renewable energy system (Marshall *et al.,* 2011). Derivation and analysis of a comprehensive picture of the environmental impacts of national consumption targets for renewable energy system, including the effects of imports and indirect land use change is highly needed. Recently, President's Council of Advisors on Science and Technology (PCAST) report recommended that US government should institute and fund a Quadrennial Ecosystems Services Trends (QuEST) Assessment. QuEST should provide an integrated, comprehensive assessment of the condition of U.S. ecosystems; predictions concerning trends in ecosystem change; syntheses of research findings on how ecosystem structure and condition are linked to the ecosystem functions that contribute to societal important ecosystem services; and characterization of challenges to the sustainability of benefit flows from ecosystems, together with ways to make policy responses to these challenges more effective (PCAST, 2011). The effect of large-scale implementation of renewable energy production including biofuel may be a provision to include in the QuEST assessment.

6.9 Eco-industrial Integrated Production Plans

Since the introduction of the industrial ecology concept and the apparent success of Industrial Symbiosis project, attention to planned eco-industrial park (EIP) development projects has grown all over the world (Allenby, 2006). Global industrial ecology is focused on shifting of industrial process from linear open loop systems, in which resource and capital investments move through the system to become waste, to a closed loop system where wastes become inputs for new processes (Ehrenfeld, 2004). In this idealized integrated industrial ecosystem, firms and organizations utilize each other's material and energy flows including wastes and byproducts to reduce the system's virgin material and energy input as well as the waste and emission output from the system as a whole, and contribute to sustainable development (Allenby, 2006). Advocates of industrial ecology suggest that by shifting the basis of industrial production from a linear to a closed loop system, these gains can be achieved. In recent years, concepts drawn from industrial ecology have been used to plan and develop eco-industrial parks that seek to increase business competitiveness, reduce waste and pollution, create jobs and improve working condition. Energy management on industrial parks can be integrated in the entire development process and park management. Maximizing efficiency is a promising local optimization issue, in which business should be engaged, stimulated and facilitated. By clustering buildings and processes, by energy exchange, collective production and joint contracting of energy services, local synergies can be intensified (Maes, 2011). Recently, the United States Department of Energy has proposed building energy parks at some of its former nuclear sites. These parks would develop technologies to enhance renewable energy sources, nuclear, coal, and others, as well as technologies to manage the waste, and transmit the energy (Greenberg, 2010) thereby, maximize the clean energy production from waste resources. These types of parks can be deployed in various regions in US, especially where substantial uranium mining (e.g. New Mexico in R-6 region) has done and the land is not suitable for any other uses.

Studies have shown that large scale renewable energy implementation plans must include strategies for integrating renewable sources in coherent energy systems influenced by energy savings and efficiency measures (Lund, 2005). Integrated Renewable Energy Parks, which is a EIP model, are macro-level renewable energy production schemes based on integrated industrial schemes and optimum resource coupling. In IREP-like energy production schemes, by limiting the input of fossil fuel into energy production and processing facility, firms can qualify for two types of incentives: generating renewable energy and reducing emission via various direct and indirect carbon offsets. Hence, the framework of IREPs will be enhanced by present and future energy policies and cap-and-trade like regulations. To obtain a meaningful reduction in GHG-emissions and to produce optimum sustainable renewable energy needs IREP-like macro-level energy production models. Further, the integration of food production industries such as dairy industry and aquaculture industry with biorefineries in IREP can bring a multitude of sustainable deliverables to society, such as clean energy and food production, renewable supply of cheap food protein supplements, health products and aquafeed ingredients (Subhadra, 2010a,d; Subhadra, 2011c; Subhadra & Grinson-George, 2011, Subhadra 2013). The principle foundations of IREP's are resource sharing, carbon neutrality, energy-efficient design, source reduction, green processing plan, anthropogenic use of waste resources for the production green energy along with the production of raw material for allied food and chemical industries. The IREP's are highly suitable for regions where several renewable energy resources are optimally available, for example R-6. These IREP model is highly relevant in a future ‟carbon constrained” business world (Subhadra, 2011a; Subhadra 2013).

CONCLUSION

With several renewable energy laws already in place and other legislative initiatives are rapidly evolving, one of the concerns is the proper understanding of the full resource potential in US with respect to natural and renewable energy resources. This paper broadly assesses the natural and renewable energy resources in US by dividing the US into various regions. The analysis based on the various parameters showed that R-6 (Southwest) with highest developmental potential and regions such as R-3, R-4 and R-5 have good developmental potential. Some of the issues related to develop an optimum pathway for renewable energy sector in these high potential regions were highlighted The major issues discussed were the need for novel federal and state polices, the need for prioritization of regions, the need for consumer energy-education and outreach, the need for new infrastructure investments, and the need for integrated resource policies, and integrated production plans. Energy security and low-carbon renewable energy production is highly needed for US as other countries such as China are progressing rapidly in this front. Any lag in policies and developmental agenda would be a severe blow to long-term US economic growth and energy technology competency.

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