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"Essays on Renewable Energy, Growth and Sustainable Development"

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Structure of the dissertation

Introduction

Paper I: *"Can renewable energy grant sustainable development in an oil fed economy?"*

Paper II: *"Simulating exogenous and endogenous technology when depletables, renewables and pollution co-exist: how to achieve sustainability?"*

Paper III: *"Bioenergy and foodsecurity: Who benefits and who loses? The importance of the ceteris paribus assumption"*

Introduction

If governments today around the world stick with current policies... the world's energy needs would be over 50 percent higher in 2030 than today...the challenge for all countries is to put in motion a transition to a more secure, lower carbon energy system, without undermining economic and social development...vigorous, immediate and collective policy action by *all* governments is essential to move the world onto a more sustainable energy path..." (IEA 2007, pg 41, selected lines).

The current energy portfolio which heavily relies on fossil fuels is not sustainable and the energy decisions of today will be essential in trying to curb climate change impacts. The need for energy diversification is a must and renewable non-polluting resources need to contribute much more to energy generation. In fact, the non-sustainability of fossil fuel economies no longer lies with the limited availability of those resources but with the greenhouse gas emission levels the current energy pattern leads to. **This thesis investigates the relationship between the availability of renewable resources and sustainability.** The thesis is divided in three papers examining some critical questions regarding renewable energy use. The first two papers take a long term perspective and investigate: How can we achieve strong and weak sustainability? What contribution does technology make? What role does substitutability between renewable and depletable resources play? How do production and consumption assumptions affect the results? The third paper takes a different viewpoint and looks at bioenergy and household level welfare impacts.

Current energy demand is mainly met by fossil fuels and consequent CO_2 concentration levels are too high; further, there is a wide divide in energy demand across regions. Fossil fuels meet 80.9 percent of energy demand today and are estimated to absorb the majority of projected demand. World primary energy demand is projected to more than double between 2005 and 2030 (see Table 1 and 2)[1]. Developing economies will be the largest contributors to this projected growth because of fast economic and population growth rates. Fossil fuels are projected to

[1] The IEA Energy Outlook presents a number of scenarios that make different policy and growth assumptions. Here we refer to their baseline scenario, the reference scenario.

meet 84 percent of the total energy demand increase. Coal is predicted to absorb a large share of the increase in demand, reaching a share of 28.2 percent in 2030 (IEA, 2007). At present, the gap existing between primary energy use per capita across regions in the World is high. OECD industrialised countries consume approximately 4.68 toe/capita[2] compared to 1.62 toe/capita in the Middle East and North Africa, 0.72 toe/capita in Asia including China and 0.6 toe/capita in Sub-Saharan Africa. Thus one sixth of today's world population consumes approximately 50% of the total primary energy supply. The global population is growing by approximately 80 million people a year and has doubled since 1960, estimated to reach 8.2 billion by 2030. Thus, pressures on the energy demand system will be increasing as countries progress, population grows and the gap in energy per capita levels narrow (WEA 2002, WEA 2004, UN 2005).

Energy related pressures on the environment have been heavily debated but, finally, the fourth IPCC assessment acknowledges that climate change impacts could be severe if action is not taken immediately. In 2005 the global atmospheric concentration of CO_2 was estimated at 379 parts per million (ppm), rising from pre-industrial level of 280 ppm. Rising energy demand under the IEA reference scenario predictions, suggest that energy-related CO_2 emissions will increase by 57 percent over the 2005-2030 reference period. The fourth assessment of the IPCC reports that CO_2 concentrations need to peak and decline thereafter in order to ensure that CO_2 concentration stabilises. If a safe CO_2 concentration level is considered to be in the range of 400-440 ppm (a potentially high target level[3]), the peak year needs to occur between 2000 and 2020. Note that the lower the concentration target, the earlier the peak in concentration has to occur (more details are reported in Table 4). Due to the science behind climate change, there are a lot of uncertainties in trying to predict future atmospheric carbon content and it is difficult to assess the levels resulting from the reference scenario energy demand increases of the IEA. Based on a number of caveats, the energy demand increases of the reference scenario should be equivalent to CO_2 concentration levels in the range of 660-790 ppm, well above the stabilization target required to avoid the most detrimental impacts of climate change (IEA 2007

[2] toe/capita are tonnes of oil equivalent per capita.

[3] Scientists disagree on what the actual safe target level of CO2 concentrations should be. The UNFCCC has set 450 ppm as a "safe" target to avoid climate change danger. Others have put forward a lower target level of 350ppm, see for example Monastersky (2009) in Nature.

and IPCC 2007). Thus, mitigation actions are needed today. In the words of the IPCC report:

"...Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels. Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. There is high agreement and much evidence that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers" (pg 19 and 20of the Climate Change 2007: Synthesis Report).

Although "low impact" energy sources are already available, they still play a minor role in meeting energy demand today. Currently, renewable energy sources[4] supply 13 percent of global energy demand, 10.1 percent from biomass and waste, 2.3 percent from hydropower and 0.5 percent from other renewables. Amongst the renewable energy sources, the largest share is taken up by hydropower for electricity generation and solid biomass for heat production, Table 3. The contribution of solar and wind energy is minimal.

This is even more surprising if we look at the technical feasibility of reverting to a less carbon intensive energy system. Azar (2005) shows that, a 400 ppm target for CO_2 concentrations, assuming high per capita energy use levels[5], is technically achievable. The solution lies in implementing energy efficiency policies that allow to reduce demand by 50 percent on the one hand, and an energy supply breakdown of 10 percent from fossil fuels, 20 percent from fossil fuel with carbon capture, 20 percent biomass and 50 percent from solar and wind, on the other. These figures do not sound unrealistic, but rely not only on a change in the energy mix, but also on a substantial increase in our ability to substitute for depletable resources.

[4] These include biomass and waste, hydropower, solar, wind, geothermal, tidal and wave energy. In IEA terminology, solar, wind, geothermal, tidal and wave energy are referred to as 'other renewables'.
[5] The main assumptions include emissions of 2 GtC/yr and a population of 10 billion using 200 GJ/yr/capita, equivalent to the level of an OECD person, and a timeline up to 2100.

In conclusion, the key is to act now, increase energy efficiency, diversify energy portfolios and improve our ability to use “low carbon” energy sources in place of the “high carbon” ones. The effort has to be twofold. In the short run, sources must be diversified and demand reduced by energy saving policies. In the long run though, as proposed by this research, energy portfolios need to change dramatically.

As mentioned, three papers constitute this thesis and the structure is as follows.

Papers I and II set up an intertemporal optimization problem in which the economy can use both a renewable and a depletable energy source in energy production. This part of the thesis builds on a large body of literature, whereby the innovative contribution is to explicitly introduce a renewable energy source and pollution in a Dasgupta-Heal type framework and study its role. The renewable and exhaustible energy sources are distinguished based on their contribution to pollution, cost, technology and availability.

In paper I we impose a specific set of constraints including a strong sustainability condition, Cobb Douglas production and exogenous technology. The strong sustainability condition requires the stock of pollution to be constant over time, equivalent to the argument that CO_2 concentrations in the atmosphere need to stabilize and remain constant thereafter. The set of assumptions allows us to obtain a closed form solution. We find that renewable resources are crucial for economic growth and that a restrictive condition on pollution needs to hold for the economy to be strongly sustainable. On the other hand, as the time horizon extends to infinity, the mere existence of renewable resources no longer guarantees strong sustainability.

In Paper II, we build on the model constructed in Paper I but release most of the assumptions made in the first paper, introducing endogenous learning by doing linked to the renewable energy resource and a wider range of consumption and production functional forms. We find conditions to achieve weak and strong sustainability. We find that renewable and depletable energy resources need to become highly substitutable and that substitution amongst resources and consumer flexibility are crucial in ensuring a weakly and strongly optimally sustainable economy.

In the context of recent commodity price surges, Paper III focuses on bioenergy and the impact of bioenergy developments on household welfare and food security in developing countries. Bioenergy will be an important energy source for some specific types of developing countries that have very limited energy access today and still rely heavily on the agriculture sector. Bioenergy is deemed as one of the causes of the price increases. When analyzing the effect of price increases on household welfare, the assumption of equi-proportionate price changes on the producer and consumer side is widespread in the literature. We show that such assumption does not allow for the analysis to be undertaken *ceteris paribus*. This negatively biases results and can lead to wrong policy indications. A methodological correction is proposed and sensitivity to the assumption is reported based on Peruvian and Tanzanian data. Conclusions on welfare impacts of price increases obtained under our proposed methodology are then presented for the case of Peru.

Table 1: World primary energy energy demand.

Energy Source	**1980**	**2000**	**2005**	**2015**	**2030**	**2005-2030 (%)**
Coal	1786	2292	2892	3988	4994	2.2
Oil	3106	3647	4000	4720	5585	1.3
Gas	1237	2089	2354	3044	3948	2.1
Nuclear	186	675	721	804	854	0.7
Hydro	147	226	251	327	416	2
Biomass and waste	753	1041	1149	1334	1615	1.4
Other renewables	12	53	61	145	308	6.7
Total	*7228*	*10023*	*11429*	*14361*	*17721*	*1.8*

Source: Reference scenario, IEA 2007.

Table 2: Share by energy source (%)

Energy Source	**2005**	**2030**
Coal	25.3	28.2
Oil	35.0	31.5
Gas	20.6	22.3
Nuclear	6.3	4.8
Hydro	2.2	2.3
Biomass and waste	10.1	9.1
Other renewables	0.5	1.7

Source: Reference scenario, IEA 2007.

Table 3: Renewable energy contribution by type in 2006 for the world.

	Municipal Waste*	**Industrial Waste**	**Primary Solid Biomass****	**Biogas**	**Liquid Biofuels**	**Geothermal**	**Solar Thermal**	**Hydro**	**Solar Photovoltaics**	**Tide, Wave, Ocean**	**Wind**	**Total**
Unit	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*	*GWh*
Gross Electricity Generation	53571	12478	145002	24655	3675	59240	1061	3120614	2781	550	130073	3553700
	1.5	0.4	4.1	0.7	0.1	1.7	0.0	87.8	0.1	0.0	3.7	
Unit	*TJ*	*TJ*	*TJ*	*TJ*	*TJ*	*TJ*	*TJ*					*TJ*
Gross Heat Production	159988	93929	302610	11617	3072	11577	132					582925
	27.4	16.1	51.9	2.0	0.5	2.0	0.02					

Source: IEA, 2009 at www.iea.org.

Table 4:

CO_2 Concentration (ppm)	**CO_2-equivalent (ppm)***	**Global mean temperature increase above pre-industrial level at equilibrium** (^0C)**	**Peaking year for CO_2 emissions**	**Global change in CO_2 emissions in 2050 (% of 2000 emissions)**
350-400	445-490	2.0-2.4	2000-2015	-50 to -85
400-440	490-535	2.4-2.8	2000-2020	-30 to -60
440-485	535-590	2.8-3.2	2010-2030	+5 to -30
485-570	590-710	3.2-4.0	2020-2060	+10 to +60
570-660	710-855	4.0-4.9	2050-2080	+25 to +85
660-790	855-1130	4.9-6.1	2060-2090	+90 to +140

* All greenhouse gases expressed in CO_2 –equivalent terms (adjusted for differences in radiative forcing); ** Based on “best estimate” of climate sensitivity.

Source: IPCC 2007 in IEA 2007.

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