How Libya could become environmentally sustainable

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Abstract
The main factors to be tackled if environmental sustainability becomes Libya's national goal are: first, to base desalination and pumping on renewable energy (e.g., solar, wind); second, to invest oil receipts to export solar electricity; and third, to achieve these two before oil or water are depleted. Because water is paramount for sustainability and economic development, if pumping fossil water and desalination become based on renewable energy, then low-cost freshwater can become the basis for sustainability. As Libya is so well placed to generate solar electricity, the most sustainable choice is to accelerate the transition to renewables before international climate treaties force coal and, later, oil to be left unused in the ground. Libya could lead in making Europe carbon-neutral through massive exports of solar electricity. This would be highly profitable for Libya and at the same time would help achieve sustainability. Quasi-sustainability of non-renewable resources (e.g., oil) could be achieved by investing oil receipts in Libya's sovereign funds, so that by the time hydrocarbons are exhausted a sustainable income is generated for Libyans in perpetuity. This could also provide social safety nets, create jobs and increase human capital formation.

Introduction

This paper outlines what environmental sustainability means for Libya. If Libya chooses to become sustainable, what are the main factors to be addressed? The main factors to be tackled if sustainability becomes a goal are: first, to base desalination and pumping on solar energy; second, to invest oil receipts to export solar electricity; and third, to achieve these two before oil or water are depleted and before signing any international agreements to prevent climate change, whichever comes first. As it is not possible to make depletable resources like oil fully sustainable, a method is suggested whereby the receipts from oil sales are invested in order to earn income which is sustainable.

Definition of environmental sustainability

Based on its definition as 'non-declining wealth per capita', environmental sustainability can be defined by the two fundamental ecosystem services – the source and sink functions – that must be maintained unimpaired during the time over which sustainability is required. This definition applies to all countries, sectors and epochs. However, this paper is restricted to terrestrial factors, hence excludes the Mediterranean despite its importance for Libya.

There are only three rules of environmental sustainability (Daly and Cobb 1994, Daly and Farley 2004) from the point of view of those focusing on the management of water and energy resources:

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- On the source side: keep harvest rates of renewable resources within regeneration rates, such as fisheries;
- On the sink side: hold waste emissions within the assimilative capacity of the environment without impairing it. Oil pollution and greenhouse gas emissions are key in Libya;
- Non-renewable resources cannot be made sustainable. But quasi-sustainability can be approached for non-renewable by holding their depletion rates equal to the rate at which renewable substitutes are created (see below).

Note that this analysis focuses on the use of water and energy and the environmental impacts of their management. The analysis does not examine the political feasibility of adopting the outcomes and conclusions.

The timing of sustainability

Several variables govern the rate at which Libya can achieve sustainability. Part of the equation depends on estimates of the stock of groundwater and oil, but these are unreliable. The optimal extraction rate of hydrocarbons is important. If the price of a barrel of oil increases substantially in the near future, then delaying peak production may be more profitable than accelerating it. However, some advise accelerating the production rate as fast as possible in view of the probability of international treaties to reduce emissions of greenhouse gas. Accelerating oil production depends on the rate at which contracts can be signed and oil fields developed. For sustainability the important rate is the transition to renewables – namely how fast wind and solar energy can be brought on line.

There are many benefits and few, if any, costs to accelerating the rate of transition to renewables as fast as possible. Delinking desalination and groundwater production from fossil fuels would be a tremendous achievement for Libya. Most of Libya's oil could then be sold and the revenue invested in perpetuity.

Conservation of water

Because of Libya's desertic nature, water is paramount for sustainability and economic development. Libya's Environmental Law 15 (Article 41) states that water is to be used economically and that technologies must be used to minimise water consumption in all activities. Conservation of water is thus the law of the land. Oil is nearly as paramount as water because it is needed to pump freshwater in the near term, until water pumps are based on solar energy.

Practically all (approximately 96%) of Libya's freshwater is groundwater, mostly (75%) from the Great Man-Made River (GMR). Most (95%) of the country receives between 0 mm and 25 mm of rainfall per year. Surface water accounts for 2.3%, while recycled sewage effluent provides 0.9%. Water from desalination is about 0.7% (1990 data). Agriculture consumes 3,800 million cubic metres (Mm^3) of water annually, or 85% of Libya's freshwater supplies.

Urban water use consumes about 400 Mm^3, or 11.5%. Industries including the oil sector consume about 150 Mm^3, or 3.5%.

The two starting points for Libya's desire for sustainability are: first, on the input side, choosing how water is pumped, either by fossil fuel or by solar pumps; and second, on the output side, striving for stringent conservation and efficiency in the use of water.

The main source of water

The GMR now provides about 75% of Libya's annual water demand (urban plus agriculture) from 1,000 wells, 2,000 km of buried 4 m-diameter pipe, with some surface water impoundments for interim water storage. GMR's first aquifer, the Kufra Basin in southeast Libya, has an estimated groundwater storage capacity of nearly 21,000 km^3 in the Libyan sector alone. GMR's first stage supplies Benghazi and fills coastal reservoirs; it was completed in 1991. Tripoli has been supplied since 1997. Ultimately GMR is expected to provide 3,000 Mm^3 annually from its 30,000 km^3 aquifers. The goal is to supply 5 Mm^3 per day to coastal populations.

Although two-thirds of GMR water was originally allocated to irrigation, increasingly it is consumed in households. Even pessimists admit the GMR has one century of function; optimists claim five centuries. (Super-optimists mention 4,000 years, Bissani *et al.* 2004.) GMR officials say it will last 50 years (Killgore 2001). Though gigantic, GMR aquifers are finite, even if their limits are not yet known. The aquifers contain fossil water many thousands of years old and are not being recharged.

The greater constraint than aquifer volumes may be the availability of fuel for pumping the water from ever deeper levels. At present pumping water up to the pipeline system from as many as 1,000 wells as deep as 2 km consumes much fuel. Once the water is in the pipeline, gravity, supported by some pumps, feeds the demand centres. The pipelines are getting longer, water levels are falling and demand is soaring. Thus the fuel consumed in pumping already is expensive for Libya and will become more so as global oil prices rise. Every barrel of oil needed for pumping costs Libya US$100 or more in foregone exports.

The sooner water pumping can be powered by renewable energy (wholly or partly) the sooner Libya will become sustainable. The transition from fossil fuel GMR water pumps to solar-energy water pumps is possibly the most important step for Libya's approach to sustainability.

Desalination of water

Libya is ranked fifth in the world in the use of desalination technologies, even though less than 2% of the annual water demand in the country is satisfied by desalinated water. Planned and under-construction facilities are expected to produce 986 Mm^3 of water per day from 21 plants.

Libya has 17 significant desalination plants. From a total of 400 desalination plants with an installed capacity of more than 100 Mm^3 per year, or 33,374 m^3 per day, actual production is only 18 Mm^3 per year (Porter and Yergin 2006), only 1% of annual national demand. Most desalination plants run only sporadically due to scaling, corrosion and maintenance problems. Three desalination plants companies went bankrupt (Alghariani 2003).

Production costs for one cubic metre of desalinated water are 0.76, 0.86 and 1.30 Libyan dinars (LYD) respectively for desalinated water from large, medium and old plants. In comparison, GMR water has a total cost of around US$30 billion, or a unit price of between 70 and 160 Libyan dirhams per cubic metre of water. The same volume produced by desalination of seawater would cost between 320 and 620 Libyan dirhams. Desalination costs are falling worldwide, but GMR costs are rising over the years.

The overriding fact is that 50% of desalination costs accrue from energy costs. Improved technology may lead to lower costs. However, desalination can be expected to consume large amounts of energy regardless of the technology. So as the cost of energy rises, it may cancel out the benefit of more-efficient technology. On the other hand, the physics of reverse osmosis mean that costs fall rapidly as the salinity of the input decreases. To desalinate brackish water may require only US$0.02 to US$0.10 per cubic metre of treated water; this makes the process much more competitive.

Desalination of water worldwide is now mostly by reverse osmosis, but this method of desalinating seawater costs about eight times more than obtaining water from conventional supplies in wet climates. Plans by the state-owned electricity company to install a 300 m^3 per day reverse-osmosis desalination plant fuelled by renewables needs to be replicated and accelerated. The world's largest solar desalination plant under construction is a 2,000 m^3 per day system in Libya, designed to be powered by wind turbines, according to Gleick (1994).

Libya's official news agency reported that the parliament had approved development of a nuclear power deal with the US to generate electricity and boost desalination. The foreign ministry was authorised in March 2007, to negotiate with the US on construction of the country's first nuclear power station. Similarly, France and Libya signed an approximately €2 billion agreement on the civilian use of nuclear energy in December 2007, including seawater desalination. While a nuclear power station would help diversify desalination energy, the possibility should be considered that its costs may exceed gas-fuelled and eventually solar-based desalination.

Norton Rose (2003) predicted a worsening shortfall of water of 1,309 billion cubic metres (Gm^3) by 2007, and there is some mention of a water crisis in Tripoli. Turkey offered to sell water to Libya after Israel rejected a similar offer, according to WorldTribune.com (11 February 2002). *Ha'aretz* reported (2 April 2003) that the Turkish government was considering an agreement to export 100 Mm^3 of water annually to Libya. Libya again discussed importing 100 Mm^3 of water annually from Turkey's Manavgat River on 18 October 2006 (www.Ha'aretz.com). Despite the high costs of tanker shipping (possibly floating in huge plastic bags), Libya may look on water imports as a supplement to desalination. The finance ministry is said to oppose importing water, since its price would be about US$0.80 per cubic metre, as opposed to US$0.50 per cubic metre for desalinated water.

Recommendations for water conservation

Although GMR water is unparalleled worldwide, some diversification of water supply for Libya would lower risks. Therefore, Libya may want to balance GMR water with desalinised water.

As GMR water becomes extracted from deeper levels and becomes more expensive, the more cost-competitive desalination water will be. Desalination costs are dropping internationally. Thus international desalination costs of US$0.60 to US$1.00 per cubic metre (excluding distribution costs) are already approximating the full costs of GMR water.

Renewable energy could be used both to pump GMR water and desalinate other water. The costs of conversion will be more than paid for by the export of the increased volumes of oil freed by the use of renewable energy. In the interim, flared gas is useful as a fuel to bridge the transition to fully-renewable energy until solar and wind energy can be phased in. Desalination could be fostered as the economics improve over the next few years, even if desalination is not yet totally competitive with GMR water (which is debatable).

As full-cost pricing of water (removal of subsidies) is phased in, the poor could be offered low-cost water up to 'average' household consumption, then progressively higher rates for water over and above that volume. Minimising the levels of arrears would help achieve social justice. They must lead eventually to restricting water to the 'average' volume. Households repeatedly in arrears should be offered debit cards for payment of water in advance.

Where brackish wells are available, brackish water could be maximised for all uses not needing high-quality freshwater. Mandating building codes for rooftop rain collection would promote conservation. Leakage losses from supply pipes and reservoirs are significant and should be controlled. A program to control leaking equipment should be kept up-to-date.

There is scope for storing water in underground cisterns and caverns with little evaporation, as has been done for millennia in the Middle East.

Conservation would be helped by restricting irrigation only to the most profitable crops and by planting trees (such as olive and date) to decrease wind, soil erosion, dust and evaporation while providing shade and food and improving soils.

Recycling and wastewater

Treating and reusing wastewater has valuable scope for expansion to promote conservation. Libya treats about 40 Mm^3 per year of wastewater. All treated wastewater is used for agriculture. As irrigation water in Libya is essentially free, there is little incentive to use it efficiently.

In the 1970s and 1980s about 40 sewage treatment plants were built near big cities in Libya, with an aggregate design capacity of 175 Mm^3 per year. Most suffer from lack of maintenance. Libya has great conservation potential by using water-saving toilets and brackish water or seawater, as achieved successfully in Hong Kong. A commendable wastewater collection system serves 97% of the population. Efficiency and conservation would be promoted by constantly adjusting the price that the industrial sector pays for water. Treated effluent is currently allocated to fodder irrigation. Profitability would be achieved by reallocating treated effluent to higher-value crops.

Allocation of irrigation water

Libya imports 75% of its food because of its harsh climate; food subsidies exceed 2% of GDP. Flour subsidies alone approximate the administrative budgets of the Ministries of Justice and Foreign Affairs combined (World Bank 2006a).

Less than 2%, or 2.2 million ha (Mha), of Libya is arable. Of this arable land about 309,000 ha are irrigated, mainly from groundwater extraction. Irrigation accounts for 85% of all water use in Libya. This raises the price of Libya's irrigated food. One source claims, 'At present, no water fees are imposed on [irrigation] water users' (FAO *c.* 1998). If so, this suggests major opportunities to boost efficiency and productivity of Libya's irrigation.

Groundwater from tube wells in the coastal agricultural zone exceeds regeneration, and hence is depleting. In addition, saline intrusion has moved inland as much as 10 km and is increasing in coastal-zone wells. Intrusion of seawater into and under coastal and relatively freshwater aquifers means management of irrigation return water and coastal groundwater will be important for sustainability.

Highly subsidised groundwater prices for irrigation of $0.03 per cubic metre (LYD 0.048) were set by decree in 1993 and are well below cost, which must be approximately $0.09 per cubic metre. Massive subsidies to irrigation water have led to inefficient allocation to low-return crops and fodder. Irrigation of fodder crops is difficult to reconcile with economic and conservation goals.

If efficiency of water use becomes the sustainability goal, following Environmental Law 15 (Article 41; Para. 4) would reduce irrigation losses, increase profits and boost efficiency. Consideration should be given on how best to balance irrigation of dates, citrus, vegetables and olives, which are profitable, against irrigating fodder. Libya might want to consider reducing water subsidies and raising irrigation water prices toward the costs of production.

In the near future expansion of GMR water, powered by renewable energy, could be allocated to irrigation. The added benefit would be in job creation, both unskilled and skilled, to manage the irrigation technology.

Domestic grain production vs. imported grain

About 25% of Libya's grain demand is satisfied domestically. What is the best balance between domestic grain and imported grain? Since it takes 1,000 tons of water to produce one ton of grain, importing grain is the most efficient way of 'importing' water. Grain is 'concentrated water'. One ton of imported grain implies importing the equivalent of 1,000 tons of water. But total reliance on global grain imports may not be the answer.

Unfortunately, grain is increasingly allocated to agrofuels, and climate change may be starting to impair grain harvests. For these and a number of other reasons grain prices for food are soaring. The 2006 world grain harvest fell short of consumption by 61 million tons, marking the sixth time in the last seven years that production has failed to satisfy demand. World carryover stocks at the end of this crop year fell to a 50-year low. Food riots this year have broken out in the Philippines, Thailand, Egypt, Morocco, Yemen, Mexico, Guinea, Mauritania, Senegal and Uzbekistan. Pakistan has reintroduced rationing for the first time in two decades. Russia has frozen the price of staples for six months. Thailand, India and Vietnam are curtailing rice exports. After widespread protests in Indonesia the government has increased public food subsidies. It looks as if only the richest nations will be able to purchase internationally traded food, and such food will be increasingly expensive and scarce.

By early 2008, wheat exceeded the US$10 per bushel level for the first time ever; corn (maize) exceeded US$5 per bushel, close to its historic high; soybeans prices reached US$14 per bushel, the highest price on record. All these prices are double those of a year or two ago. As continuation of these price trends seems likely, Libya will have to allocate more of its budget to food imports. In the future, assuming Libya is achieving sustainability in water, a balance will have to be chosen between having money to purchase world-market grain (the rational choice today), as against some domestic grain production. When Libyan water becomes fuelled by renewable energy, domestic grain production will become much more economical.

Achieving efficient irrigation

Irrigation efficiency elsewhere has been increased with drip irrigation and micro-sprinklers, which can achieve water use efficiencies of 95%, compared to efficiencies of 60% or much less in flood irrigation. Good practice shows that on-farm water productivity generally doubles as soon as drip irrigation is phased in. Drip irrigation cuts water use by 30–60% while boosting yields by up to 50%. Libya's State of the Environment (2002) depicts the least-efficient steel beams spraying the sky with valuable freshwater above orchards. Micro-irrigation was developed in the 1960s and has spread rapidly to cover an estimated 2.8 Mha worldwide, a 50-fold increase over the last 20 years but still only about 1% of the world's irrigated area. The potential for expansion is enormous.

Sustainability of food supply

Much of Libya's oil profits go toward increasing food imports for its growing population. At present it clearly makes sense to export abundant and expensive hydrocarbons for foreign exchange to enable Libya to import 80% of its food. But that would change if Libya wants to become sustainable. Libya imports about 1.4 million tons of wheat a year but the price is soaring.

Libya's basic exchange of oil for food is rational. International foodstuffs are still available, but the international grain prices are reaching record levels. Importing 80% of a nation's food requirements has an element of risk. In addition, importing so much food and subsidising it so heavily decreases job creation within Libya. Although it would not be economical for Libya to aim for self-sufficiency in food, some balance would be beneficial. Much food can be economically produced, partly based on treated and recycled water, in greenhouses surrounding cities. Libya's constraint of sandy soils could be avoided in hydroponics; hence efficiencies in water, energy and fertilizer could become attractive. Another opportunity is hydroponics fed by renewable energy desalination water. Job creation would be an added benefit.

Government water management

There is no overarching water ministry or authority in Libya responsible for strategic planning or coordination of all aspects of water use and supply. Water management is fragmented. A proposal is circulating to create a water coordination and integration ministry.

Conservation of energy: oil, gas and renewables

As the mainstay of the Libyan economy the hydrocarbon sector – oil and gas – contributes more than 72% of the GDP in nominal terms, 94% of export earnings, and 93% of government revenues (World Bank 2006b). Libya has low production costs (down to US$1 per barrel in places), oil of high quality, proximity to European markets, well-developed infrastructure and vast unexplored reserves.

The amount of exploitable hydrocarbons remaining is not known with any precision, as much crucial planning would be based on that estimate. Proven reserves, the largest in Africa, will last for at least 20 years, or 60 years at current production rates.

Libya has major potential to increase the production and export of hydrocarbons. Oil production is constrained primarily by lack of upstream investment. The revenues from increased production and export of oil and gas could finance job creation, thus reducing the 25% unemployment rate.

Libya has approximately 1.13 trillion cubic metres (Tm^3) of proven gas reserves; this is expected to rise to approximately 1.98 Tm^3 as gas reserves have been less explored than oil reserves. Production exceeds 42.5 Mm^3 per day of gas; 50% is sold, 30% re-injected, 15% flared and 5% used in-field. Libya's 595 km submarine Greenstream gas pipeline to Italy exports up to 8 Gm^3 per year. Greenstream's capacity can be boosted to 10.9 Gm^3 annually from its current 7.93 Gm^3.

To the extent that European consumers are trying to reduce emissions of greenhouse gas, Libya's natural gas exports will command a premium because it emits a fraction of the greenhouse gases from coal and oil. If Libya's hydrocarbon exports accelerate Europe's switch from coal toward gas, that will be a major benefit in meeting the UN Kyoto Treaty targets. With oil exceeding US$100 per barrel in 2008, extraction rates will probably rise sharply.

In any event Libya has several decades (some say 40 years) to diversify away from oil and become sustainable. Note that one estimate of groundwater depletion is also about 40 to 50 years. The worst-case scenario is the risk of both oil and groundwater becoming problematic simultaneously. Depletion of oil and groundwater are tightly linked: As groundwater becomes deeper, more energy will be needed for pumping. If groundwater requires more pumping energy at about the same time oil is becoming scarce, the problem is stark.

Saif al-Islam el-Qaddafi summarised it well: 'The day will come when oil will run out, and if we wait for that it will be too late' (*New York Times*, 23 September 2007). Libya's 'several decades' until groundwater and oil become scarce is sufficient time to reach sustainability, but only if it is vigorously and promptly sought as a national priority.

Recommendations

As Libya is so well placed to generate solar electricity, the most sustainable choice is to accelerate the transition to renewables before international treaties force coal and later oil to be left unused in the ground. Libya could lead in making Europe carbon-neutral through massive exports of solar electricity. This would be highly profitable for Libya, and at the same time it would help the world move toward climate stability.

Libya's dependence on energy exports, now over 80% of the national budget, is increasing. Today's oil production of 1.8 million barrels per day could be boosted to at least 3 million barrels per day. Conservation of energy is important to facilitate the transition to a sustainable economy. Gas flaring of 9.91 Mm^3 per day wastes a precious non-renewable resource, harms human health and exacerbates global climate change and desertification. Meanwhile, non-hydrocarbon exports are negligible and declining; only the small tourism sector is growing. Pursuing sustainability as a national priority before groundwater and oil reserves become scarce would be prudent. Exportation of natural gas could be maximised.

Electricity

Libya's 5.2 gigawatts (GW) of electricity production, with a peak load of 3.875 GW, is mainly (68%) oil-fuelled. Natural gas fuels 32% of electricity generation. Libya has about one million electricity customers. Electricity consumption is about 39% domestic households, followed by 17% industry, 14% commercial, and 12% agricultural.

Libya's power demand is growing fast (approximately 8% per annum) and is projected to reach 10 GW by 2020. During the summer of 2004, Libya was hit by widespread blackouts as power plants could not keep up with demand. To prevent such blackouts in the future and to meet surging power consumption, the government planned to invest US$3.5 billion by 2010, building eight new combined-cycle and steam-cycle power plants. Construction had started at only a couple of the new plants because of serious financing problems due to heavily subsidised electricity prices (around LYD 0.02 per kilowatt-hour (KWh); consumers pay the equivalent of US$0.02 whereas the production costs exceed US$0.03) and arrearages.

Much electricity is wasted because 40% of consumers do not pay, and electricity prices are kept artificially low: electric power is 60% subsidised. This has led to over-consumption, especially for air-conditioning. Subsidies for electricity and gasoline undermine conservation and sustainability. Transportation fuels also are subsidised, further reducing incentives to conserve. Subsidising electricity will hamper all attempts to phase in wind and solar energy. There are far more efficient means of supporting Libya's poor than through energy subsidies. In any event, such subsidies benefit the rich more than the poor. Ballut and Ekhlat (1998) calculated that conservation could reduce demand by 20% or 50 million barrels of oil by 2020.

Solar and wind energy are under-exploited for electricity generation. This is odd, as Libya is so exceptionally endowed with solar energy. The total solar energy reaches 7.1 KWh/m^2 per day in places. Most of southern Libya averages over 6 KWh/m^2 per day of global radiation, whereas northern Mediterranean countries receive less than 3 KWh/m^2. Libya has a potential 140,000 terrawatt-hours (TWh) per year of solar electricity (Ekhlat *et al.* 2007).

Libya has used 50 W to1,000 W wind pumps in many oases since 1940. A 10 KW model wind pump was installed in 1993. A 25 megawatt (MW) electricity generation wind turbine is expected to enter service soon. Libya's wind resources, potentially 15 TWh per year, were mapped and inventoried in 2003. Coastal sites average wind speeds of over 6 m per second at 40 m height.

Wind energy has come of age. Global installed wind power now exceeds 100,000 MW. Climate change risks (Goodland and El Serafy 1998; Goodland 2007) and the desire for energy security have encouraged one in every three countries to generate electricity from wind, with 13 countries now exceeding 1,000 MW of installed wind energy capacity. Algeria is developing 6,000 MW of solar-thermal electric-generating capacity to export to the European grid via the undersea cable. The electricity from this single project is enough to supply the residential needs of a country the size of Switzerland. Tunisia already generates 20% of its electricity from solar.

Sustainable energy

The paramount consideration for environmental sustainability is the amount of energy needed to ensure adequate supplies of freshwater, whether fossil water or though desalination. Both sources are very energy-intensive. This fact emphasises Libya's two priorities for sustainability: first, stringent water conservation and second, reducing the cost of water through solar energy.

Major oil consumers claim renewable energy is not yet fully competitive with fossil energy. That is mainly because fossil energy externalises major environmental costs (sulphur pollution, acid rain and greenhouse gas emissions). The regulatory, technological and commercial trends are all on the side of renewables.

Solar energy

Libya generates little solar electricity. The main type of solar energy is passive solar, such as rooftop hot-water systems that are low-tech, low-maintenance and low-cost. There may be a niche market for solar cookers and solar crop driers. Active solar is mainly solar thermal electricity.

In March 2007 Spain inaugurated a 50 MW solar-thermal electricity plant, using molten salt to store heat for nocturnal generation. This plant will soon generate enough electricity for all of the city of Seville – some 180,000 homes. The same plant sited in Libya would generate about twice as much electricity as in Spain because of more favourable insolation. Kurokawa *et al.* (2006) show the feasibility of big photovoltaic systems in deserts. Solar thermal concentrates sunlight to generate steam from high temperatures (over 800°C) for gas turbines, and then steam powers the co-generation turbines. Solar electricity has very low environmental impact. In densely populated or agricultural sites, the main impact is land use. This need not apply in Libya.

Photovoltaic (PV) electricity is useful for small water-well pumps, isolated uses and small household lighting. PV production has increased 25% per annum for the past decade and 45% in 2005 alone. The costs fall 5% to 8% each year. The price of one watt of solar electricity fell from US$20 in the 1970s to less than US$3 today. Qatar even has PV parking metres.

Libya's PVs are growing in size and number, now exceeding 690 KW. PV has powered cathodic protection of the Dahra to Sedra oil pipeline since 1976. PV is widely used to energise communication repeater stations; nine of Libya's 100 repeater stations were PV energised by 1997, and four of these are still running as of 2007. El-Agailat's irrigation pumps have been solar powered since 1983. Many oases now have PV-powered water pumps. More than 6,000 domestic PV-solar heaters have been built since 1980. PV rural electrification began in 2003.

Now Libya commendably reaches 99% of its population with electricity. The General Electricity Company of Libya (GECOL) has valuable experience in rural electrification based on PVs in 340 remote villages. PV costs less for such villages than both grid connections and the diesel option. GECOL plans to build a 1 MW PV grid-connected pilot plant in 2007, and possibly ten more later on; this schedule could be accelerated. The experience is there: PV is proving to be reliable, with very low running and maintenance costs, and is highly cost-effective. The need now is to ramp up PVs, especially for water pumping. Standard PV packages of 10 KWh per day could be widely deployed. PV displacement of diesel could become a national priority.

Libya's huge potential for solar-hydrogen storage of energy is mentioned in the literature (Broesamle *et al.* 2001, May 2005, Müller-Steinhagen and Ruhter 2005), but seems less urgent than solar thermal.

Opportunities for energy conservation

Building codes could reduce energy and water use, especially in new offices and hotels. Libya's traditional mudbrick buildings are blissfully cool without air conditioners. Insulation and shade (from trees) are important and low-cost elements of conservation (Ealiwa *et al.* 2001). 'Smart metres' price electricity during peak demand (often for mid-day air conditioning) when solar panels peak in power output. Full-cost pricing could be phased in while expanding low-cost lifeline rates for the poor.

Appliance efficiency standards for air-conditioners, fans, refrigerators and water heaters would conserve much electricity. Mandatory automatic shut-offs when appliances are not in use would help greatly. Raising vehicle kilometres-per-litre of fuel standards would promote sustainability at the same time as being profitable. Optimising the balance between air freight, fast ferry freight and the potential for rail would boost sustainability, as would finding the optimal balance between private automobiles and mass transit. Tripoli's 20-passenger minibus is a good solution if systematised, made safe and on schedule.

Libya's solar-thermal export opportunities

(Sources: Mariyappan and Anderson 2002, Müller-Steinhagen and Nitsch 2005, Mills and Dey 2001)

Libya could replace all GMR water pumping and all desalination energy with solar-thermal. Libya would then become the biggest seller of sustainable electrical power to Europe in perpetuity. Libya would gain also from not producing any greenhouse gases. Greenhouse-free electricity would command a premium from European consumers. The electricity can be transmitted by submarine High Voltage Direct Current (HVDC) to Europe. Libya receives the almost optimal sunlight of 3,000 KWh/m2 at 23°N, which is excellent for base-load generation. Solar-thermal is competitive with oil at US$60 per barrel; oil sold for over US$100 per barrel in 2008.

Wind energy

Wind is the world's fastest-growing energy source, with an average annual growth rate of 29% over the past ten years. In contrast, over the same time period coal use has grown by 2.5% per year, nuclear power by 1.8%, natural gas by 2.5%, and oil by 1.7%. Worldwide wind power production has increased 25% per year over the past decade and reached 60,000 MW in 2005.

Wind power is the cheapest form of new electricity, costing between US$0.04 and US$0.07 per KWh and falling fast. Overall the cost of wind power has decreased by nearly 90% since the 1980s, to US$0.04 or less per KWh in prime wind sites. In some markets wind-generated electricity already is cheaper than electricity from conventional energy sources. The cost of wind power has fallen because of advances in technology, declines in the costs of financing wind projects, and the economies of scale of turbine and component manufacturing and construction. Modern turbines are taller and have longer rotor blades than the turbines of 20 years ago, allowing them to produce up to 200 times more power.

Since the 'fuel' for wind power is free and unlimited, 75% to 90% of the costs of generating electricity with wind lie in manufacturing and constructing wind turbines and connecting them to the grid. Once turbines are installed, the remaining costs are primarily turbine operation and maintenance, land-use royalties and property taxes.

North African countries are beginning to develop wind power and have installed 310 MW of wind capacity. Egypt and Morocco have installed 150 MW and 60 MW of wind capacity, respectively. The prices of wind-generated electricity are more stable and not subject to the price volatility of fossil fuels. Wind power supports local economic development since the jobs, royalties and tax revenues from wind-generated electricity production tend to stay in the community.

Wind turbines, especially on the Mediterranean coasts and offshore, also are promising. Since wind is inexhaustible it offers long-term energy security that electricity derived from non-renewable fossil fuels cannot. Wind water pumps at the farm level are in use with potential for expansion.

Wind-generated electricity could be beneficial for Libya because the electricity transmission distances from where the winds are strongest to where the energy is needed, are so short. In addition, wind electricity complements solar-thermal electricity by generating more at night after the sun has set.

Conservation in transportation

Libyan motor vehicles consumed 36 million litres of fuel in 1992, the latest figures available. Of that total, 73% is benzene/petrol and 27% is diesel. Owing to the specifics of Libya's five refineries, gasoline has to be imported, so its conservation and substitution are important for the economy. Retail gasoline prices are subsidised at about half the Mediterranean average for 2004. Once national agreement has been reached on making transport sustainable, the rest is relatively straightforward. A judicious combination of incentives, grants and standards will make Libya a leader in sustainable transport.

The Environment General Authority (EGA) and the municipalities regulating fuel efficiency and safety standards of mass transit would accelerate sustainability. This could be modestly subsidised to reduce car usage and hence air pollution and to preserve oil for export. Free mass-transit passes should be offered, first to the elderly, the handicapped, the vulnerable and children, then to all poor households.

Vehicle fuel efficiency
Raising vehicle efficiencies by kilometre per litre standards or by 'Corporate Average Fuel Economy' (CAFE) standards for all new vehicles, combined with incentives to phase out gas guzzlers is specifically provided for by Environmental Law 15 (Article 16). The most powerful incentive to improve efficiencies and promote mass transit is to phase out current fuel subsidies. As Libya imports all vehicles at present, the easiest way of improving fuel efficiencies is for EGA to require them as part of the importation permit process.

Congestion taxes or time-of-day user road costs can prevent congestion, time and fuel wastage while improving the quality of life and the environment. In view of Libya's pleasant climate, ecotourism will be fostered and air pollution decreased by making ancient city centres car-free, at least during the day.

Rail transport
Rail is the most efficient form of transport, as it uses the least energy per ton of freight or per passenger. Solar-thermal electricity facilitates rail links. The Railway Project, the 4,800 km trans-African rail network planned to link Tunisia and Egypt, was expedited in 2006. The US$9 billion Railway Project has been given national priority by Prime Minister Dr Baghdad Mahmudi. The first two sections of the planned 3,170 km railway in Libya are starting to take shape.

Marine transport
Libya's reliance on ocean freight, containers and refrigerator ships means the ports and export terminals should be as efficient as possible. Efficient ferries would help in the transition to sustainability. High-speed catamarans and hovercraft may be feasible, as the slow Malta ferries deter passengers.

Air transport
Air freight is the least fuel-efficient transport method. Libya's most sustainable methods of transportation would be marine and rail. Highways would come next, while air transport would be the most expensive choice.

Sustainability and population
Although Libya is the richest nation in North Africa, with a 2005 per capita income of nearly US$10,000, one million of its 5.67 million citizens (2006 census) live in poverty. Libya's population growth rate, more than 3.3% yearly between 1960 and 2003, is one of the highest in the world.

Libya's population is 86% urbanised, one of the highest rates in the world, and the rural exodus continues. In virtually every industrial society where women are well educated and have ready access to jobs, they average two children or fewer. Libya's 2006 census showed that only 30% of Libya's women participated in economic activity. Libya's 88% adult literacy rate is one of the highest in Africa, although women's literacy rate (71%) lags behind men's (91.8%).

Libya's official unemployment rate of 17% is thought to be an underestimate. Assuming it is about 25%, and assuming half of the population is under 20 years of age, labour market tensions will intensify, according to the World Bank (2006a). The 3.3% population growth rate means each person can earn a shrinking slice of the resource pie. Such a high rate makes it more difficult to attain sustainability, because population increases intensify water and energy use, and per capita exports decline. More effluents and wastes damage the Mediterranean, which is already polluted and overfished. This degrades the quality of daily livelihoods, especially of the poor. Libya may want to choose between spreading investments thinly over a larger population or more effectively over a smaller one.

The Oil Reserve Fund

It is difficult to convert non-renewable resource extraction into any semblance of long-term sustainability, but quasi-sustainability can be achieved. Libya's Oil Reserve Fund is very important for any approach to sustainability. Libya is thought to have saved between US$33 billion to US$50 billion as of 2007. This fund is the only way for Libya to achieve sustainability before the oil and possibly the groundwater run dry.

Permanent funds, part of 'sovereign wealth management', are well-known financial mechanisms created to ensure that oil receipts benefit the people in perpetuity. They also prevent allocation of all oil receipts to current expenditures, prevent the 'Dutch disease', and reduce the risk of inflation. Ideally, high-savings countries and those rich in oil receipts liberalise their economies, and allow their own citizens to invest for themselves, rather than paying sovereign wealth fund managers to do it for them. But we are not at that point yet. Sovereign wealth funds seem here to stay at least for the short term.

The best goals of sovereign wealth funds include: firstly, saving resources for the future, so that by the time the hydrocarbons have been exhausted a sustainable income is available for Libyans in perpetuity; secondly, stabilising oil price volatility; thirdly, diversifying national revenues; and fourthly, designing effective social safety nets, creating jobs and increasing human capital formation in-country.

Sovereign wealth funds are preferably focused on the sustainable development of their own internal economies. Investment in external economies should be kept balanced in order to diversify and spread risk, while maintaining development of their own economies as the priority. Diversification of Libya's economy away from oil exports, and towards sustainability in water and energy, value added, domestic processing, job creation, possibly by accelerating oil refining and petrochemicals, will be important for such funds. Besides what has already been achieved, and as a fine complement to the GMR, sustainability would be accelerated by investing most funds nationally to make water and solar energy sustainable.

Libya may have about 50 years to become sustainable. Libya is unusual in that it has the financial and other resources to become sustainable fast. Accelerating the development of solar and wind energy will enable Libya to export hydrocarbons for much longer.

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