WHAT IS THE SPEED OF ENERGY TRANSITION?

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Introduction

The headlines like "coming age of renewables" or "phasing out of coal" seems likely to happen in a matter of years. Despite having these changes already initiated, the speed is a matter of question for investors as well as consumers.

After Paris agreement, "stranded asset" discussions were widespread. The oil and coal companies have been warned to be careful for having stranded assets. Making matter worse, as the commodity prices plunged, it became an imminent threat for shareholders. From the IPO of Saudi Aramco to the bankruptcy filing of coal powerhouse Peabody, the economic fortunes of the fossil fuel companies are closely monitored and analyzed.

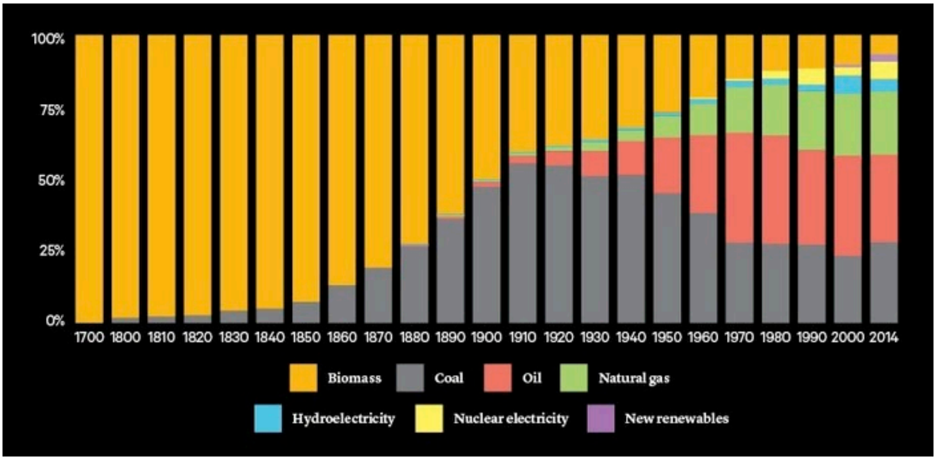
In this article, the speed of energy transition within an analytical framework will be investigated. By using data from IEA World Energy Balances database, historical energy transition speeds will be examined for the world and different countries. A hypothetical country's energy transition to solar and electric cars is briefly introduced in the last part.

The findings suggest that transition speed is constrained by technology in several parts of the energy system (infrastructure, production, consumption). One of the fastest transitions in OECD countries happened in France. Even in Germany, pace is slower than expected. The developmental stage is also affecting the speed.

Primary Energy Transition

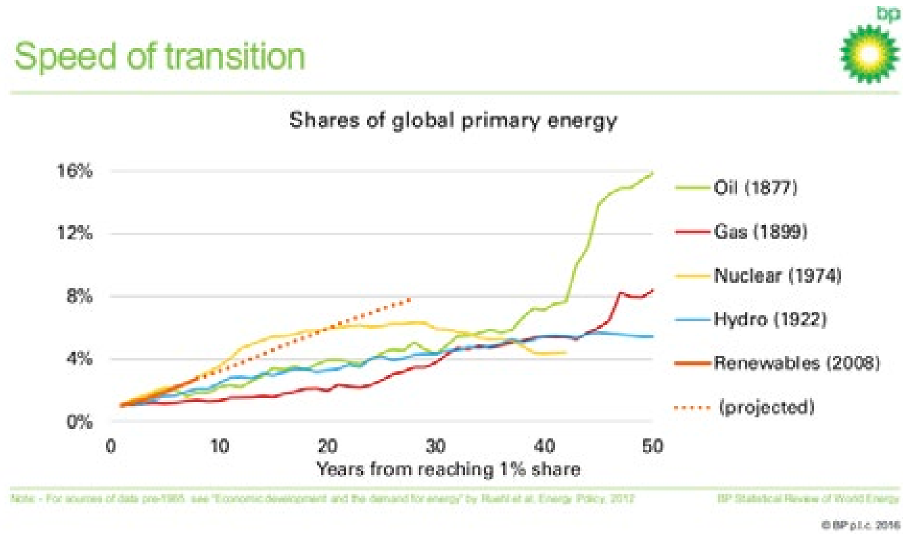
World's energy transitions are driven by both technology and policies favoring technologies or resources. Having those resources doesn't guarantee the accelerated utilization of that particular fuel, because it is closely linked with the technological tools to utilize it. A recent example can be given for natural gas. Natural gas needs pipelines to be delivered and heaters for consumption. Pipelines are one kind of infrastructure technology while liquefaction or LNG plants, ships and regasification units are other competing or complementing ones. So, what will be the speed of transition to natural gas? It depends on all those factors mentioned above.

Daniel Yergin's The Prize book[1] starts with two important technologies that paved the way for oil dominance in the 20th century. The first one was refining, the second one was drilling. These technologies increased oil's share against coal's. However, the new fuel also nurtured new technologies such as petrol cars. Coal however, didn't wiped out completely, but prices and developing countries' needs supported its resistance.



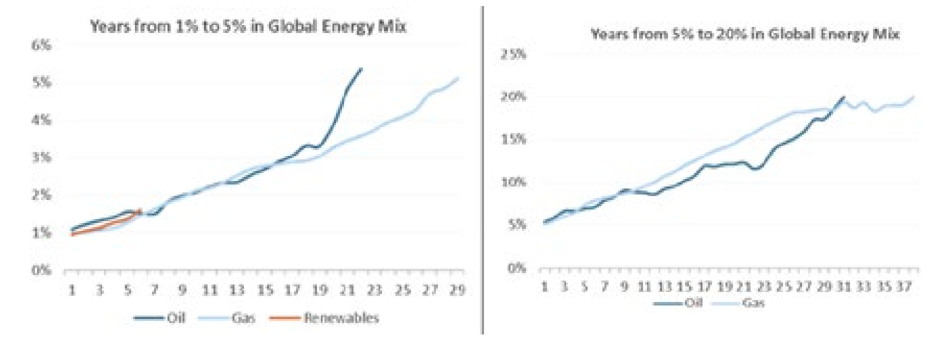
Primary energy transitions in global energy mix[2]

In BP, Statistical Review of World Energy, "Speed of Transition" slide[3] is a summary of historical pathways. It took more than 50 years for oil to reach %16 share in global primary energy. One wonders, whether this data should be looked more globally or countrywide. Since global change will be much slower than the frontier countries.



BP Presentation slide on energy transition

Coney Kazokoglu from FG Energy[4] has two graphs. First graph showing the progress path from 1% to 5% of global energy mix. The second graph is the change of this share from 5% to 20%.

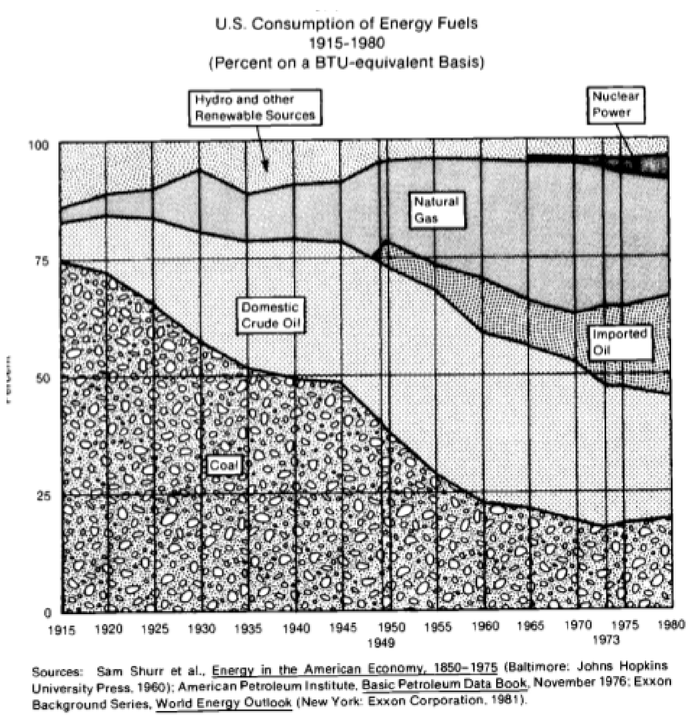


The speed of change in the share from 1% to 5% and 5% to 20% in global energy mix

These global energy transitions may hint us about the speed of the transition but country level data also needs some consideration. Long term historical datasets are not readily available for most countries, but developed countries like USA can be helpful for extensive research.

USA's Energy Transition

USA's energy transition between 1915-1980s is a high-speed transition compared to world transition above. In 1915 coal was 75% of energy mix, by the year 1940 it was close to 50%. 25% drop in 25 years has happened. Meanwhile crude oil and natural gas increased their share.



US energy transition from 1915-1980s[5]

Between 1945-1958, US economy moved towards liquid and gaseous (fluid) fuels from solid fuels. Coal price dropped 7.4% as well as its share ebbed from 43% to 22%. A 21% drop in 13 years.

The other important conclusion from the above graph is how oil embargo of 1973-1974 and 1979 energy crisis affected US fuel consumption patterns. Thus, the return of coal after 1973 is worth mentioning.

Another element in transitions is the energy security concerns. Energy security concerns may overturn an ongoing transition in a limited way. Although no major coal breakthroughs happened during 1970-1980s, coal preserved its place and even gained some share. Can there be a complete reversal of an expected energy transition? Historical evidence does not provide sufficient material for a conclusion.

Examination of Historical Data

The second part of the article, examines world and country level data to contemplate on the speed of change. For this study, IEA database was used. IEA World energy balances database includes data from 1960s to 2015 for OECD countries. For non-OECD countries, the data starts from 1971. The energy balances of countries include primary fuels and electricity imports or exports. The dataset is quite detailed, however for the sake of simplicity a much briefer subset is examined. The subset used in this analysis includes:

- Coal, peat and oil shale,
- Primary and secondary oil (oil products)
- Natural gas
- Nuclear
- Renewables

Electricity (electricity line in the primary energy supply) has not been included in the analysis, since the values represent import or export balances. It is included on the primary energy balance to correct for trades. It is not a real indicator for energy transition.

Methodology used is as follows:

1. Share of each primary resource in total mix has been calculated.

2. This share has been compared with the share for the previous year and 10 years ago.

3. Maximum positive change among the share of any primary resource is recorded as “1 year” or “10 year” increase. A positive number is seeked, since a gain of the new comers is generally the loss of incumbent resource. Therefore, gains are better indicators for our purposes.

“1-year increase in the share of primary energy supply” means, fastest growing one primary resource for that period has increased its share by a given percentage. This increase translates into decrease in other primary resources’ share. “10-year increase” follows the same logic.

A dynamically linked spreadsheet is constructed to allow selection among countries. The countries selected are chosen based on the criteria of size, development path as well as geographical proximity.

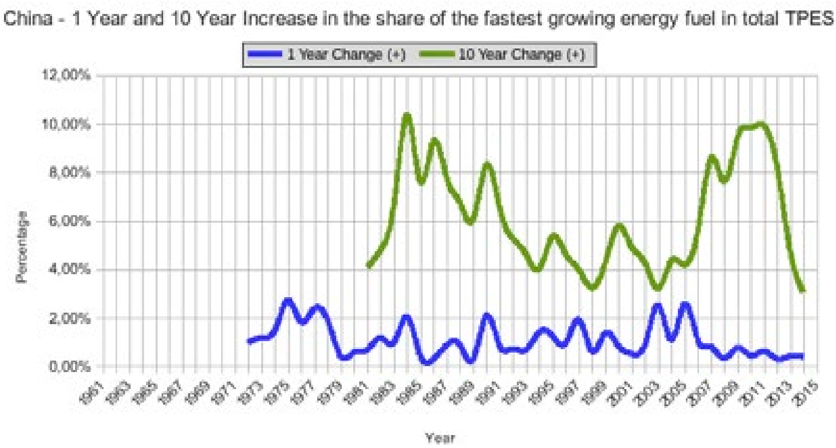
1 year change and 10-year change will show the pace of transition in the short term and relatively long term. Generally, 1 year change is observed to have a much smaller value than the 10-year change.

The world level data represents two fundamental increases. In the chart below, the first peak of 1985-1991(green line) is the rise of nuclear compared to 1970s. Much larger second peak around 2011 is the rise of coal by developing countries. For the last 40 years year-on-year change didn't exceed 1% frequently. The maximum 10-year change is 5.7%, approximates to roughly 17 years for full transition.

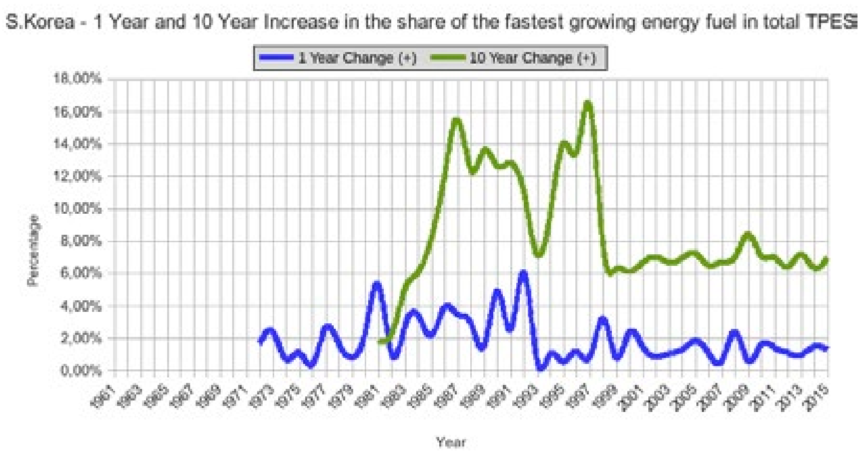
USA's energy transition resembles world until 2000s. But after 2009 the shale revolution and natural gas's rise can be traced from the graph below. Compared to world, due to its decreasing weight in world energy consumption, USA is diverging from the overall picture.

USA's maximum year-on-year change has happened in 1967 with natural gas with 2.2%. During the 1980s coal, has gained considerable share of maximum 5.4% compared to 1970s. In 1977 and 1978, just before the 1979 energy crises oil gained share but lost afterwards. As mentioned, in recent years natural gas made considerable gains compared to 2000s.

China however has frequently seen more than 1% gain in the total energy mixture. Most of these changes happened in coal's share in total primary energy supply. Recently this change has lost some steam.



South Korea is one of the countries achieving high speed growth. The first high speed transition has happened with the increase of nuclear, the second change in the late 1990s is due to oil.



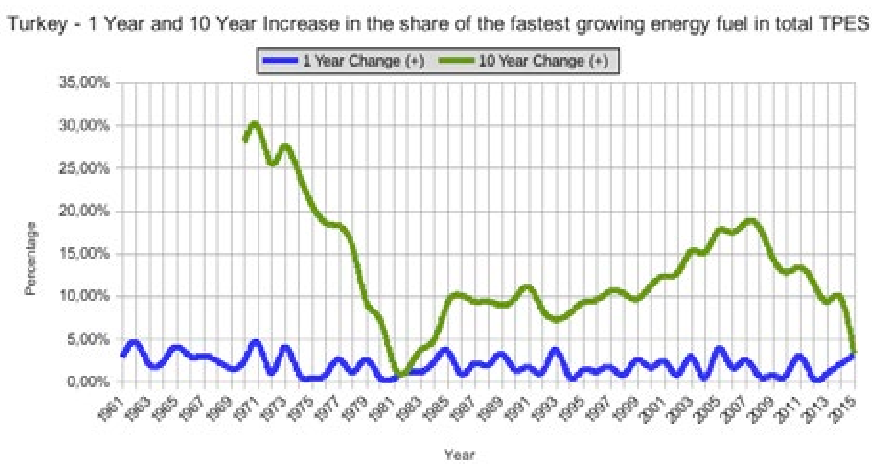
When it comes to nuclear, France has a particular importance in understanding energy transitions. The country has established a dedicated nuclear program to move away from fossil resources. In a sense, this looks like a renewables transition since both resources don't involve fossil resources and they both used mainly for power generation.

France has achieved 25% and 30% change in 10 years. The first peak of 1971 and 1972(just before 1973 oil embargo) is due to oil gaining share in consumption. The second one is nuclear gaining share from oil. During that period, nuclear has surpassed 5% y-o-y change in its increase in general energy mix.

Germany on the other hand, despite Energiewende, hardly sees more than 10% increase in total mix change in 10 year periods. In 2005 share of renewables in TPES was around (since I excluded electricity in this analysis) 5%, this increased to 12%. 7% increase in total mix.

Chile on the other hand has shown one of the most impressive changes in energy transitions. The peak in 2004-2005 is due to natural gas. The recent y-o-y changes are a complex interplay between renewables (2012-2011), coal (2008-2007), oil (2014-2013) and natural gas (2009-2008).

Finally, Turkish energy transition first experienced and increase in oil and then natural gas. Recently coal, oil and natural gas dominates the maximum y-o-y changes.



All these country specific examples show that every country has its own energy transition path within a much slower global energy transition. The countries with more renewables have seen a more complex interplay due to weather events (drought etc.). For developing countries, renewables may have biomass accounting for a larger percentage than hydro, solar and others. However, France's nuclear transition is one of its kind growing from 2.7% in 1977 to 32.6% in 1987. It is a dramatic change with an impressive speed.

An Empirical Transition Example

In the last part, a hypothetical country with 100 mtoe (million tons of oil equivalent) TPES (total primary energy supply) is presented. That country has no net demand increase and supplying all its energy needs from oil. Therefore 100 mtoe is totally supplied from one single fuel, oil.

To clarify certain concepts, TPES is the total primary energy supply. It is the energy supplied to that country from domestic and exported resources. A fraction of TPES is used as an input to transformation sector (refinery, power generation etc.). This transformation outputs secondary fuels and electricity. So, the difference between TPES and transformation sector input, with the addition of transformation sector outputs is considered total final consumption (TFC).

For this setup, 100 mtoe supply's 30 percent is used for power generation with uniform 50% efficient power plants. The rest is directly passed to the final consumption. The electricity generated from primary energy resources is also added to that sum. The simplified balance sheet of this hypothetical country is given below:

	Million Ton Oil Equivalent
Total Primary Energy Supply(1)	100
Power Generation(2)	-30
Total Final Consumption(3=1-2+4)	
Electricity(4)	15
Transport(5)	35
Other(6)	35
Sum (4+5+6)	85

A Simplified energy balance sheet for 100% oil consuming hypothetical country

In a real-life balance table, only demand sectors will appear under TFC. Electricity should be in columns. Since there is only one kind of fuel used -namely oil, in this economy, electricity is converted to rows.

Now, this country decided to invest in solar panels at t=0 and within a certain time frame achieves 35 million households having 1kW solar panels each. The capacity factor for these solar panels is roughly 20%(1800 hours per year). The total solar capacity is 35,000 MW, and total electricity generation will be (35000 MW * 1800 hours/year) 63 Terawatt-hours.

From IEA's unit conversion site[6], 1 MTOE equals 11.63 TWh. So, 35000 MWs generate 63 TWh that is equal to 5,4 mtoe/year. This is avoiding 10.8 mtoe of oil consumption in power generation. So as total final consumption does not change, but TPES (1) drops to 94.6 mtoe (-10.8 mtoe plus 5,4 mtoe solar as primary energy)

So, when this country decides to move away from oil consumption to solar panels in electricity generation, with 35000 MW it can only change 5,6 mtoe of primary energy supply. A change of -10% in oil consumption is substituted with an increase in renewables in 5%. This is due to thermal generation efficiency assumption of 50%.

1 mtoe of renewable-sourced generation increase in electricity substitutes 2 mtoe's of oil consumption. Total primary energy supply drops by 2 mtoe (reduced oil consumption and supply) and increased by 1 mtoe (solar as primary energy).

	Oil only (MTOE)	Oil +35000 MW panels (MTOE)
Total Primary Energy Supply(1)	100	94,6
Power Generation(2)	-30	-19,2
Total Final Consumption(3=1-2+4)		
Electricity(4)	15	15
Transport(5)	35	35
Other(6)	35	35
Sum (4+5+6)	85	85

The result of shifting from oil to solar panels in power generation in that hypothetical country.

This is the supply side effect of this transformation. Now demand side effect will be discussed with electric cars. What if this country shift all its passenger car transportation to electricity from oil products?

The main assumptions in this setting are petrol engines are 30% efficient and only 30 mtoe of transport fuels (5) is for road transport. 50% of road transport is used in passenger cars. Electric cars, with their batteries are assumed 90% efficient. Half of road transport fuels (30/2=15 mtoe) is consumed in passenger cars. Only 30% of this energy is transformed in to mobility services (15*0.3=4.5 mtoe). Setting constant, the energy required for mobility services, electricity needed for the same activities are (4.5/0.9=5 mtoe).15 mtoe of oil mobility converts to 5 mtoe of electromobility.

	Scenario 0	Scenario 1	Scenario 2
MTOE	100% Oil Consumption	Electric Cars (electric from oil)	Electric Cars (from Renewables)
Total Primary Energy Supply(1)	100	95	90
Power Generation(2)	-30	-40	-30
Total Final Consumption(3=1-2+4)			
Electricity(4)	15	20	20
Transport(5)	35	20	20
Other(6)	35	35	35
Sum (4+5+6)	85	75	75
Total Balance (mtoe)	100	95	90
Oil	100	95	85
Renewable	0	0	5
Total share(%)	%100,00	%100,00	%100,00
Oil	%100,00	%100,00	%94,44
Renewable	%0,00	%0,00	%5,56

The final energy balance sheet of both supply and demand side scenarios are given above. Electricity from renewable energy reduces both TPES and TFC, since renewables are assumed to have 100% efficiency. Shift from oil to electric cars primarily reduce TFC, thus TPES drops as well. With electric cars oil consumption in transport (5) is converted into electricity consumption (4). Still the transition pace doesn't reach even 10%.

Conclusion

Energy transition requires technology transition. Technology transition is induced through new inventions or government policies due to energy security, environment or others. Therefore, energy transitions by themselves are bounded by technology (including infrastructure) and the impact of policies.

The technological change means a change in infrastructure, appliances, equipment. To retire existing machine park for the sake of technological change may not be economically efficient for the decision makers. The sunk costs, amortizations, asset lifetimes are all considerations to be carefully examined.

In this article, the speed of energy transition is investigated from historical records. There are important results:

1. The pace of change depends on the country's development path and status (developing or developed)

2. Shale gas revolution in US is one the major energy transitions happening around the world

3. World is much slower in terms of energy transition, developing countries are faster (since their technology base is newly forming)

4. Transitioning to electricity from other fossil fuels decrease primary energy needs

5. Transitions in power sector among fossil fuels is twice as large compared to renewables since fossil fuels are used with an efficiency factor. (3 units of coal produce more than 1 units of electricity)

6. France's nuclear transition in 1980s with 30%(nuclear) change in the share TPES is remarkable and an example of the fastest energy transition to non-fossil resources.

7. With French example in mind it may take at least 30 years to fully change an energy system

8. German example is roughly 10% change in renewable share in 15 years. More than 100 years to have a 100% renewable energy system

9. Electric cars may not save the day but increase efficiency of the energy system substantially

10. Roughly world has achieved a maximum of 6% change in 10 years time since 1971.

Therefore, the speed of transition may not be that fast, despite having all the technologies readily available. But the way transition happens can be more disturbing than its speed.

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