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RESEARCH ARTICLE

REVISED Standardizing a unique renewable energy supply chain: the SURESC Model [version 3; peer review: 1 approved, 1 not approved]

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Abstract

This theory-building research intends to dig into the renewable energy industry and drawing from research on learning curves and energy policies, proposes a way to speed-up the energy shift from our fossil-fuel dependency to a green economy. Even though standard economic frameworks suggest that markets and not policy makers should decide winners and losers, we urge to accelerate renewable energy competitiveness, proposing that by limiting the number of maturing renewable technologies where resources are allocated to at government level, we reduce the time within which renewables will achieve technological price parity with fossil fuels. In turn, by analyzing the energy demand and supply curves, the study suggests that this action will also mediate the relation between quantity and price, shifting only the supply curve, leaving the demand curve unaffected. It continues by proposing the *standardization of a unique renewable energy supply chain* model, defined as the SURESC model, relating the indirect effect of limiting the number of maturing technologies to allocate resources, to achieve renewable price-parity with conventional energy sources faster. This is a preliminary theoretical study intended to provide a holistic approach to a known problem.

Keywords

Research and Development, Carbon-free Technology, Energy Policy, Energy Shift, Renewable Energy, Energy Standards, Learning Curve

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Any reports and responses or comments on the article can be found at the end of the article.

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REVISED Amendments from Version 2

This is a complete revised version, where most of the discursive arguments were eliminated to focus on the SURESC model itself. The SURESC model has also expanded, providing more details on its conclusive structure. All real-life examples were deleted for future debates. This new version is focused on the creation of the SURESC model only.

Any further responses from the reviewers can be found at the end of the article

Introduction

Brown energy and dependency

“Despite the growing use of commercial energy, the world faced very considerable fuel poverty. Many remain without access to electricity and to modern cooking fuels” [1, p. 3].

In the world’s geopolitical puzzle, energy plays a key role defining each piece and a driver to seek for global prosperity and security². Not all countries produce enough energy to impact the world’s geopolitical scenario, but the global energy industry affects the geopolitical interests of all countries³. In fact, for every 10 percent of oil price reduction, the world’s GDP grows 0.2 percent⁴. As seen in Figure 1⁵, fuel such as petroleum and coal (fossil-fuels), account for more than half of the entire energy consumption source today, making it a strategic commodity for geopolitical bargains.

Figure 1. Global Primary Energy Consumption by Energy Source. (Source: U.S. Energy Information Administration, 2019.)

Forecasts for the near future do not seem to foresee any change, as even though renewable energy will largely increase by 150% by 2050, energy consumption will also increase by 50% driven by the Asian market⁶, thus by 2050 petroleum and coal will still be accounted for 47% of the entire energy consumption source (Figure 1). We need to change this trend urgently!

Not least, the impact to the environment for such amounts of fossil-fuel consumptions is well documented⁶⁻⁹ and is responsible for today’s climate change⁹. In fact, Höök and Tang⁹ suggested that as fossil energy and climate change are strongly correlated, a solution must be found by treating them as “interwoven challenges necessitating a holistic solution”

(p.1). Considering Höök and Tang⁹ work, this study intends to develop a holistic approach towards this well-known phenomenon, and underlines the importance of a common, standardized eco-friendly solution where all major resources should be canalized in order to obtain a faster energy shift (from fossil to renewable) than forecasted today. As we will discuss, no solution is perfect, but we need to balance pros and cons prioritizing global warming mitigation processes, which is one of our major responsibilities to guarantee a sustainable future.

Dangers of unbalancing the energy geopolitics

“Even with renewable energy and energy efficiency, markets and not goodwill to arrest climate change, largely determine the path of investment”³.

Even though renewable energy technologies are an extremely attractive energy replacement, as we will determine later in this research, fossil-fuels are hard to die. Business leads the way, and we will require a degree of human resources management similar to the one used in the cold war when this shift will happen³. The uneven distribution of the world’s natural resources causes great inequalities and attract states and private organizations to aspire access grants to resources in foreign territories¹⁰. In fact, even though many international agreements on renewable energies have been signed widely (e.g., UN Framework Convention on Climate Change, Kyoto Protocol, Paris Treaty), only few countries seem to be on track for a long-term total decarbonization strategy. Europe (27 countries) is a positive example, as with its Green Deal intends to achieve zero emissions by 2050. However, countries like the US alone have passed from being the 3rd biggest oil producer in 2008, to be the biggest oil producer in the world in 2019¹¹, nearly doubling its production in 10 years.

The need for a standardized energy stream model

“The disrupting elements of rapid change can be mitigated by common goals and a clear roadmap where incumbents join new players in implementing a low-carbon global energy transformation roadmap” [12, p. 20].

In the past years we have seen new renewable technologies and new renewable concepts rising at an astonishing rate. Today, we are producing (or potentially produce) green energy from wind, solar (PV and CSP), hydropower, biomass, geothermal, oceanic (tidal and current), cellulosic ethanol, artificial photosynthesis¹³ and more, and yet, none of these technologies have reached fossil-fuel price parity.

The allocation of resources to realize these countless renewable technologies are massive, each with standalone projects (most of which are immersed in regional realities), lacking a holistic vision⁹ to boost-up and turn into the leading energy feedstock of the future. Standardization could be an important part of this process but is dependent on the maturity of the technology. Quebec’s Normalization Bureau¹⁴ define standards as a set of agreements among players of a given industry defining characteristics and rules tailor-made for that industry using

benchmarks from field's collective knowledge. Standardization means to understand and approach a problem in an agreed way (as a voluntary action), based on field knowledge and studies, and can leverage an innovation journey that can lead to excellence¹⁵. Many studies on standardization have shown how standards are important to enhance the development of the industry involved¹⁴, from medicine^{16–18}, to HR¹⁹, to Oil&Gas²⁰, to IT^{21,22}, all industries have standardized themselves with time. Moreover, standardization diffuses knowledge, increases predictability and reduces uncertainty and risks¹⁵, key strategic factors for small and medium enterprises (SME).

The energy sector is extremely complex, data is sometimes not available²³ and economic models depend on geopolitics, R&D advancements, competitive alternatives, subsidies and/or taxes, externalities, industry's supply and demand elasticity and other factors that rapidly change with time²⁴, thus, are hard to determine. Moreover, the energy sector is heavily politicized, where usually the fossil fuel supply chain is subsidized (from supplier's governments) and taxed (from demander's governments) whereas green energy is generally subsidized to help it achieve competitive traits²⁵. Policy makers are trying to incentivize a green economy, but we are far from a real shift, as most forecasts have been missed, and we continue to increment the global usage of carbon energy despite all efforts. In 2017, total subsidies to the renewable energy upstream touched 166B\$ globally (between private and public)²⁶, with an increment of 7.09% production from the previous year²⁷, equivalent to 442 TWh of extra power generated, and forecasts aim at 192B\$ subsidies for 2030²⁶. In the energy context these numbers aren't even close to sustain an energy shift, as in 2017 global energy demand grew 543 TWh from 2016²⁸ driven by the Asian markets, yet renewables alone couldn't cover this need, lacking 101 TWh of power generation that has been supplied by carbon fuels. As suggested by the US Energy Information Administration²⁹, by following this trend our carbon emissions will continue to rise rather than fall, and our carbon dependency will be maintained^{3,5,10}. Furthermore, standard economic framework suggests policymakers to apply policies seeking for price parity in order to achieve competitiveness among energy sources. Nevertheless, price parity between green and brown energy may not be enough if economic models don't account for fossil fuel price response to renewables, as governments producers of fossil fuel may use their price buffer created from taxes and royalties as a response to push fossil fuel prices yet lower²³. This suggests that to shift to a green economy, renewable's price target should aim lower than the current fossil fuel benchmark and its economic models should foresee a strong economic response from its competitors. Technocrats and economists have spent thousands of hours creating models that would incentivize renewable energy deployment, and despite all our knowledge and efforts, we are behind in our green workplan, and our planet seems to be warming up faster than predicted³⁰. Global warming puts our external models (social, environmental, economic, etc.) under a large dose of stress which will consequently unbalance these

systems. In non-stressful situations, it would be correct to leave to markets and time the burden of a "natural selection" of technologies, but in today's environmental pressure, we can't afford to wait for a technological breakthrough anymore, governments should model conventional economies with current technologies and regulations to create non-convex economies with convenience equilibria through R&D and taxes/subsidies. We need to act by maximizing all resources and create a coordinate globalized network of protocols that will help to speed-up this shifting process. This concept is not new to the literature and can be partially found in the Carbon Leakage theory³¹, which states that in the absence of a global coordinated climate change policy, industries relying on fossil fuels as their primary energy source may relocate their premises in countries with less restrictive policies.

"Extremis malis extrema remedia" (Latin saying). The literature seems to point towards a mix use of renewable energies solution^{9,12,32–35}, and even though standard economic framework suggests that markets and not policymakers and energy geeks (like myself) should decide winners and losers, I propose that there is a direct positive relation between the number of renewable technologies subsidized at the government level and the speed with which these technologies can achieve price parity with fossil fuels. In other words, the greater the number of renewable technologies our governments subsidize, the more we increment the time within which these technologies will take to reach price parity with fossil fuels. Diminishing the number of renewable technologies to subsidize will increase resource allocation to selected technologies which consequently will speed-up its deployment and price parity achievement.

Limiting the number of technologies

"Governments have been very creative in imposing price control, what is needed is to show the economic costs of those actions and evaluate fewer damaging alternatives" [36, p. 675].

It is important to underline that this is a theory-building research³⁷, and not an empirical study. The intent is to provide a theoretical framework that may serve as a base for future empirical studies.

Learning curves play an important role to understand maturing industries such as renewables, as the sizes of the investment needed for a certain renewable technology to reach technological price parity (learning investment) with fossil fuels may define the time to achieve this goal³⁸. In this context, research and development (R&D) can diminish learning-by-doing investments in different ways³⁹, pushing the learning curve down by curve-shifting or curve-following (for more references on curve-shifting and curve-following please consult³⁸), diminishing the learning investment. Even R&D innovation catch-up could act as a catalyser but requires continuous efforts through the establishment and adequate support of competence-creating units⁴⁰.

Figure 2. Green technologies learning curves based on learning-by-doing.

Expanding on Shayegh *et al.*³⁸ learning curve for Solar PV on a learning-by-doing bases (without R&D) represented in Figure 2. Fossil fuel unit cost of generation has been set at a fixed price of 50 USD/MWh, supposing it has reached its maximum learning point where cumulative quantity will not affect unit cost (benchmark). Solar PV has a learning quotient of 23%, intercepting fossil fuel line (price parity) with a future cumulative quantity (power deployed) at over 1000 TW. On the Solar PV line, the continuous line represents historical data for Solar PV technology, the dot represents status quo, and the dotted line after the dot represents forecasts. The area between the Solar PV line (in all its length) and the fossil fuel line in Figure 3 (ABC) is the total amount of learning investment needed to reach price parity. The area within the dotted line and the fossil fuel line represents what yet needs to be invested (L_{tot1} = the difference between the total amount to be invested ABC and the total amount invested so far ASD):

Figure 3. Solar PV learning curve based on learning-by-doing.

$$\overline{ABC} - \overline{ASD} = \overline{SBCD} = L_{tot1} = L_{tot}$$

$\overline{ABC}$ = Total learning investment to reach price parity

$\overline{ASD}$ = Total learning investment historically allocated

$\overline{SBCD}$, L_{tot1} = Total learning investment that needs allocation

L_{tot} = Sum of the total learning investments among selected technologies that needs allocation (only Solar PV, $L_{tot} = L_{tot1}$)

Now we introduce a second renewable technology, onshore wind (Figure 4):

$$\overline{WECF} = L_{tot2}$$

$$L_{tot1} + L_{tot2} = L_{tot}$$

Figure 4. Solar PV and onshore wind learning curve based on learning-by-doing.

By introducing n technologies, we have:

$$L_{tot1} + L_{tot2} + L_{tot3} + \dots + L_{totn} = L_{tot}$$

Setting L_{tot1} as the smaller area, we have $L_{tot2} = L_{tot1} + C1$, where $C1$ is the difference between L_{tot2} and L_{tot1} ($L_{tot2} - L_{tot1}$).

Therefore,

$$L_{tot1} + (L_{tot1} + C1) + (L_{tot1} + C2) + \dots + (L_{tot1} + Cn - 1) = L_{tot}$$

$$nL_{tot1} + \sum_{n=1}^{n-1} Cn = L_{tot}$$

$\sum_{n=1}^{n-1} Cn$ represent the sum of the area differences between the area $\overline{SBCD}$ (solar PV learning investment needed) and the

other renewable technologies areas, and therefore is a constant and can be simplified as **Ctot**. **n** represents the number of technologies.

$$nLtot1 + Ctot = Ltot$$

Ceteris paribus but **n** and **Ltot**, so that **Ltot** becomes a function of **n**:

$$Ltot = Ltot1n + Ctot$$

Where **Ctot** > 0, **Ltot1** > 0 and **n** > 0.

This function represents the total amount of learning investment required for a set of renewable energy technologies to reach fossil fuels price parity. Usually, learning curves are indeed curves and not straight lines, but to the purpose of this exercise, the result would not change.

Continuing; every year both the private sector and the public sector allocate finite resources into the learning investment of renewable sources. These resources can be in the form of equity, subsidies, credit, loans, studies, etc. and are finite in nature (166B\$ only in 2017's subsidies as per Tylor²⁶). To simplify our calculations, let's idealize a *constant* yearly resources allocation (**RA**) to the learning investment **Inv**, and an equilibrium in the distribution of resources among technologies. This means that, every year (**t**), the total learning investment **Ltot** required to achieve price parity decreases of a value of **RA**.

$$Ltot(t1) = Ltot(t0) - RA ; Ltot(t2) = Ltot(t1) - RA ; ... ; Ltot(tz) = Ltot(tz-1) - RA$$

$$*z = \frac{Ltot}{RA}$$

On the **Inv** axes of Figure 5, we have the amounts of resources (manhours, subsidies, quantity control protocols, etc.) converted into equivalent B\$ as a function of time (**t**). The **RA** line represents the constant resources allocated year by year to the renewable industry by the private and public sector.

Figure 5. Effect of resources allocation into a single technology.

In Figure 5 we can see the amount of possible **RA** converted in USD as a function of time:

$$Inv = Ltot - RA$$

We now substitute **Ltot**:

$$Inv = Ltot1n + Ctot - RA$$

Price parity will be achieved when **Inv** = 0, this means when $t = \frac{Ltot}{RA}$, and by substituting **Ltot**:

$$t = \frac{Ltot1n + Ctot}{RA}$$

As we can see, on a learning-by-doing process, as the number of technologies requiring learning investment increase, time to achieve price parity increases too. There is a direct, positive relation between time and the number of technologies where resources are allocated. Investing into R&D would shift the learning curve down, acting as a negative moderator between **t** and **n**. This means that as the sum invested into R&D increases, both time and learning investment decrease. Let's demonstrate this claim:

Following Shayegh *et al.*³⁸ research, we find that investing in R&D will diminish initial investment costs **Ltot** and will push our learning curve down (for both curve-following and curve-shifting). In our model, it means that we diminish the initial **Ltot** by an **X** amount provided by the R&D process resulting into a new **R&DLtot**²⁰. Thus:

$$R\&DLtot = Ltot - X$$

We now substitute **Ltot** with **R&DLtot**:

$$t = \frac{Ltot1n + Ctot - X}{RA}$$

As **t** is a function of **n** (**t(n)**), **X** will act as a negative moderator to this function (Figure 6). As **n** is a positive integer greater than 0, to minimize **t**, we should allocate resources to R&D for **n=1**.

Figure 6. Model of the importance of resources allocation to specific technologies.

Considering that we are discussing at government level, another obvious result shown in this equation is that time is negatively related to the size of the resources allocated **RA**. This means that as more resources governments allocate, faster will parity price be accomplished (and vice versa).

We have found evidence to support that technological price parity between renewables and fossil fuels will be reached faster if limited government resources would be allocated to a restricted number of technologies. Reaching technological price parity means decreasing unit cost of generation price and increasing cumulative quantities too. We now need to apply this find to demand and supply renewable energy curves and see how the market would react by increasing and decreasing the number of technologies **n** we allocate resources to. Renewables produce electricity; thus, renewables' commodity is electricity. General demand and supply linear curves in an *ideal market* are represented by the following inverted functions for both demand and supply:

- Demand: $P = a - bQ_d$
- Supply: $P = \alpha + \beta Q_s$

Ideal markets require perfect competition, property rights well established, information availability, low externalities and no decreasing average costs as production increases²⁴. We will adapt from Dahl's²⁴ coal demand and supply curves to electricity as main commodity, where in ideal markets the author describes **b** and **β** as the slope (elasticity), and **a** and **α** as the sum of the following parameters:

Demand **b**

- Price of substitutes to electricity (-Pse), such as natural gas used in stoves rather than electric stoves;
- Price of complements to the commodity (Pce), such as electric heaters vs gas heaters;
- Price for the technology for electricity use (+/-Tcu), such as electric cars vs diesel cars. This parameter may be positive or negative depending if the electric technology is cheaper than the alternative technology;
- Price of the output produced (-Pop). Prices of services using electricity as feedstock such as fun-parks, electric go-karts, and others;
- Energy policy (+/-Pol). It depends on the policies in place, positive for subsidies and negative for taxes;
- Number of buyers (-#buy)

$$*P = (Pse - Pce + / - Tcu + Pop + / - Pol + \#buy) - b(Q_d)$$

*Inverted curve: **Q_d** is the demand quantity and **P** is the price

Parameters in the demand curve has no direct effect with the production technology. Demanders only know supplier's selling price. The demand curve will not be altered by altering **n**.

Supply **β**

- Price of factors for producing electricity, such as labor and capital (-Pf);
- Price of similar goods that power plants could produce (-Psim). If oxygen or chlorine prices increase to a point where using electricity for electrolysis would provide more profit than selling electricity directly, green power plants could be enticed to change production;
- Price of by-products or complements of electricity production (Pb), which in renewables do not apply;
- Production technology (Tc), technical changes should reduce costs and increase production;
- government coal policies (+/-Pol), they could incentive or disincentive the industry;
- the number of sellers (#sell);

$$*P = (-Pf - Psim + Tc + Pb + / - Pol + \#sell) + b(Q_s)$$

*Inverted curve: **Q_s** is the supply quantity and **P** is the price

Tc represent the technical changes throughout time; the technological advancement pace of a specific technology that will determine a cost reduction and an increase in production.

$$Tc = \frac{\text{Number of Technical Changes}}{\text{Time}}$$

In the **P(Q_s)** function, **Tc** acts as a positive moderator between **Price** and **Production** (quantity), shifting the supply curve to the right (Figure 7), by increasing production but maintaining price.

If the timeframe of **Tc** is set to be the timeframe within which we intend to achieve price parity with a competitive technology, we can finally find a relationship between **n** and **Price**.

Figure 7. Model of how **Tc** affect the **P(Q_s)** function.

Keeping constant the number of technical changes required to achieve price parity, by diminishing time, we increase T_c (and vice-versa). Thus, time within which to achieve technological price parity is negatively related to T_c . Having this last relation set, we can propose the final SURESC model seen in Figure 8.

Figure 9 represents the shift in the supply curve when n varies. By increasing n , the supply curve will shift to the right, and vice versa, by diminishing n , the supply curve will shift to the left (in energy markets, both demand and supply are believed to be inelastic ($b < 1$)^{24,41,42}).

Figure 8. The SURESC Model.

Figure 9. Ideal demand and supply renewable energy curves and shifting effect of selecting fewer technologies.

Conclusion

It's important to underline the fact that there is no perfect solution to the energy transition, that any technology used will have its pros and cons, breakthroughs may come from excluded ones, and that economic frameworks strongly suggest a diversified portfolio of technologies to increase success rates. Nevertheless, among maturing technologies, the application of the **SURESC model** could speed-up the energy transition with available technologies. Time is of essence in the battle to save our environment, and we need to adapt rapidly with the tools we have today. Technological breakthroughs can arrive at any point in time, but Earth's no-return temperature point (estimated within an average increase in global temperatures between 1.5°C to 2°C⁴³) has a set date and is rapidly approaching. Consequently, it's my understanding that public resources should be used to speed-up the energy transition process by canalizing most of the resources towards an existing maturing technology and leave the private sector to apply resources to find alternative technology solutions while a strong incentivized energy transition is taking place.

Applying the SURESC model would have a profound impact on the entire energy supply chain. First, renewable systems would have to switch from a decentralized model to a centralized one, with the introduction of concepts such as of smart grids and system flexibility (daily and seasonal). The entire chain will have to be standardized (with clear engagement policies) and monitored by a regulatory authority which would guarantee a correct application of the resources and operations. Renewable sources and energy carriers would have to be selected according to geographical regions, efficiency, and power demands among maturing technologies. Alternative technologies would have to be left for the private sector to develop. This is an issue some countries are facing today, and the application of a SURESC model at the government level could help to provide a clear and final long-term energy strategy.

For example, in 1992 Italy announced the first incentive mechanisms to develop renewable sources power systems in the country⁴⁴. The incentives did not limit the technology used, nor the size, and obliged the energy operators to receive any power produced by any renewable source (single and multiple source). Today, as a result of this unstandardized energy program, Italy's major energy transmission grid operators must deal with thousands of small producers from different sources (mostly solar PV and onshore wind), which provide a portion of the electricity to the energy grid in "droplets", at available production times (which differ from demand times) and where the energy systems itself are not prepared to have neither a flexibility trait nor a smart-grid implementation. The results are:

- Loss of efficiency
- A non-optimized system
- The need for large investments in electrical accumulators
- A disordered availability of power
- A disordered localization of production sites

These constraints will keep renewable energy price high, extending price parity time with brown energy sources. Italy's energy carrier companies are now aiming to build a centralized energy model which will include a system flexibility trait and a smart management of the receiving power, optimizing the entire system. At the same time, these institutions are requiring to policy makers to develop laws that will regulate production and standardize power influx. This is a partial SURESC model application example, which provides a sense of the problem and where limiting the number of technologies to use would close the model gap. Italy is one of the signatories of the Paris Treaty, and consequently must quadruple its renewable source production by 2030 and be a carbon-free emission country by 2050. A SURESC model implementation could help to achieve these goals faster.

Recommendations

The SURESC model per se will speed-up the energy transformation process but it may not be enough, as it requires governments coordination with coordinated legislations³¹ creating non-convex economies with convenience equilibria through R&D and taxes/subsidies. Even though standard economic framework suggests that markets and not policymakers and energy geeks should decide winners and losers, to speed-up the energy shift process, governments should incentive a restrictive technological resources allocation policy to achieve a roadmap designed to implement the SURESC model. Furthermore, investments in new oil and gas explorations and the development of new certified reservoirs should be heavily discouraged. In 2019, new investments made on the oil and gas upstream only, summed up at an astonishing 505B\$, compared to 166B\$ of subsidies globally allocated to the renewable energy upstream industry, and keeps rising at an average of 4% on a year base²⁸. If that money would have been invested on a clear road map, SURESC could play an important role, and the energy shift could become reality at a faster pace. The issue is not to only mitigate new emissions, but to transition the existing ones to renewable sources and contemporarily quench new energy needs, as we are already producing more CO₂ than the earth can possibly absorb. Perhaps, a possibility would be to pair the SURESC model to the ineffective carbon credits⁴⁵ formalized by the Kyoto protocols of 1997, and relaunch them as a new green strategy. This opens the opportunity to new research topics.

Limitations and future studies

As a preliminary study, this theory-building research is intended to provide a theoretical framework on variables that can potentially affect time to achieve a green energy transition. There is the need to test this model with real data, opening an opportunity for future studies. Furthermore, the study doesn't account for technological breakthroughs that can be achieved at any point on time and could potentially disrupt the SURESC model itself. Unfortunately, technological breakthroughs are an unpredictable solution for a predicted problem (climate change), while the SURESC model is a predictable solution for a predicted problem. Last, the study does not account for possible

economic and political implications on applying a SURESC model at a government level, opening another opportunity for further studies.

Data availability

All data underlying the results are available as part of the article and no additional source data are required.

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Open Peer Review

Current Peer Review Status:

Version 3

Reviewer Report 15 November 2021

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Jatin Nathwani

Waterloo Institute for Sustainable Energy (WISE), University of Waterloo, Waterloo, Ontario, Canada

I have reviewed the revised paper & it is a substantial improvement. I have no further concerns.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 15 Nov 2021

Emiliano Finocchi, Temple University, Rome, Italy

Thank you for your time and consideration. Much appreciated!

Competing Interests: No competing interests were disclosed.

Version 2

Reviewer Report 09 September 2021

<https://doi.org/10.5256/f1000research.54508.r92086>

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Jatin Nathwani

Waterloo Institute for Sustainable Energy (WISE), University of Waterloo, Waterloo, Ontario, Canada

1. This article is not of indexing quality. It conflates many issues and there is little clarity in the flow or, neither is there a logical argument from a key proposition to a convincing conclusion.
2. There is a wide literature and many citations and references which lack focus.
3. Although some of the sub-paragraphs in a section, as stand-alone items are correct, as a reader it is difficult to ascertain the linkages or relevance.
4. The statements on geopolitics of energy are very much reflective of an opinion piece in a newspaper editorial. It is not clear whether there is a cogent flow to the next section and so on.
5. The section on learning curves is well-known and the idea that R&D will improve learning curves together is well recognized. What is not clear is how the scale of implementation of the technologies will reduce the costs and become competitive with the barriers that the fossil fuels impose on the system. How does any of this link to the SURESC model and the figures are conceptual line diagrams? There appears to be no data behind the figures.
6. In several sections of the article, there are many citations. These are more or less correct as cited but the question I have is: so what? We know the properties of Hydrogen, we know the properties of ammonia & so on. What is entirely unclear is a case for why or how it may offer a sustainable pathway for a cleaner energy future.
7. In summary, this paper is not well written and is not of a high enough standard for indexing. I was expecting a critical analysis of the supply chain of a renewable energy pathway and instead what we have is more a disconnected literature.

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

No

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 27 Sep 2021

Emiliano Finocchi, Temple University, Rome, Italy

Thank you Jatin,
Your comments are welcome. I believe you're right, going through the paper after a while I may understand your perspective. I will revise it and upload a third version.

Competing Interests: No competing interests were disclosed.

Reviewer Report 03 March 2021

<https://doi.org/10.5256/f1000research.54508.r79638>

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Michel Noussan

Fondazione Eni Enrico Mattei, Milan, Italy

Giacomo Falchetta

Fondazione Eni Enrico Mattei, Milan, Italy

The author claims that the peer review is “written from a biased source and questions the integrity of the reviewer itself”. We wonder what the reviewer exactly means by “biased source”. We can safely reassure the reviewer that no gender/nationality/affiliation/journal/topic bias affected our screening of the manuscript and that our common aim is that of a constructive process to generate quality scientific content. Our comments might sometimes sound a bit direct as they go ‘right to the point’, but there is no point in taking comments ‘personally’.

While the author has responded to some of our comments, the changes to the manuscript were limited to minor corrections to some typos. Thus, we still believe that the quality of this paper is not suitable for an international publication and we cannot recommend its indexing. The author presents a “model” but without any description of the calculation process, and its conclusions do not seem to be reproducible. He claims that “the theoretical model I present should be tested with empirical data on a second study (including a sensitivity analyses), opening an opportunity rather than a flaw.”. We appreciate this indication and we believe this should be reflected clearly both in the introduction (aims and scope of the paper) and more widely in the conclusion and discussion of future research.

Moreover, the author argues that some figures are drawn directly from Shayegh et al. Generally it is correct to build on assumptions from others' peer reviewed work BUT 1) these assumptions should not be taken 'blindly' but critically evaluated in the context of the work carried out and 2) looking at Shayegh et al.'s figure 2 (from which the author builds her own figure 2), I notice they do indeed have units on the axis, which are still missing in this paper's figure 2.

One key aspect that we highlighted is the efficiency of the ammonia supply chain, which is at the basis of the suitability of this solution, especially when compared with a hydrogen pathway, proposed by the author in his model. Specifically, referring to the 72% efficiency, this value is not a result of the Nayak-Luke work mentioned by the author, since this work is simply referencing this value, which is in turn obtained in the work by "Wang, G., Mitsos, A. and Marquardt, W. (2017), Conceptual design of ammonia-based energy storage system: System design and time-invariant performance. *AIChE J.*, 63: 1620-1637. <https://doi.org/10.1002/aic.15660>¹". In this work, as specified by the title and the methodology, a simulation model is proposed with a theoretical optimization supporting a conceptual design. In fact, two separate results are given: 72% and 64% (with a set of assumptions given by the authors), and citing only the highest one is already a questionable choice. We are not questioning the validity of this study here. However, we are questioning the choice of the author of basing all his model on a single value, from a theoretical study on a potential pathway (which is not implemented today in real operations), without further research. From a scientific point of view, a proper sensitivity approach would include other studies. As an example, please consider the paper "S. Giddey, S. P. S. Badwal, C. Munnings, and M. Dolan, Ammonia as a Renewable Energy Transportation Media, *ACS Sustainable Chemistry & Engineering* 2017 5 (11), 10231-10239, DOI: 10.1021/acssuschemeng.7b02219²", which presents a more comprehensive description of different ammonia pathways, with roundtrip efficiency values from existing and potential applications in the range 19%-50% (when considering best-case scenarios for each application).

Concerning the discussion on the comparative advantage, the author claims: "I assume that in a global warming scenario, we all win, or we all lose" as a justification for the paper not considering political implications and assuming the collaboration of nations rather than competition among them. Unfortunately, this is not an assumption which seems to describe the current status of climate negotiations, where incentives of countries are not aligned because of heterogeneous social cost of carbon (Ricke et al., <https://www.nature.com/articles/s41558-018-0282-y>³) and impacts (Pretis et al. <https://royalsocietypublishing.org/doi/10.1098/rsta.2016.0460>⁴) across countries. While we appreciate that this aspect is hard to model explicitly, we believe that it should be highlighted as a limitation of the proposed model.

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Is the work clearly and accurately presented and does it cite the current literature?

No

Is the study design appropriate and is the work technically sound?

No

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

No

Are all the source data underlying the results available to ensure full reproducibility?

No

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Michel Noussan: energy technologies, energy policy; Giacomo Falchetta: energy economics, energy modelling

We confirm that we have read this submission and believe that we have an appropriate level of expertise to state that we do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Version 1

Reviewer Report 18 January 2021

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Giacomo Falchetta

Fondazione Eni Enrico Mattei, Milan, Italy

Michel Noussan

Fondazione Eni Enrico Mattei, Milan, Italy

The aim of the paper may be of interest, given the importance of the subject in the current debate on the energy transition. Unfortunately, the quality of this paper is not suitable for an

international publication. The author presents a theoretical “model” (I would rather call it framework, by the way) but without any description of the calculation process (which we suspect was not carried out, i.e. the framework has not been tested against real world data), and its conclusions do not seem to be reproducible. The selection of the ‘most suitable technology’ at page 18 seems not to be grounded by a scientific analysis but just based on a qualitative discussion, which is at odds with introducing what the author calls ‘a model’. Also, there is poor documentation on some key parameters/values considered. In particular, most of the figures for ammonia do not seem to be reliable. The efficiency of 72% is wrong, and the cited source (50) is not dealing with ammonia at all. Considering the ammonia supply chain, a total efficiency of 72% seems rather hard to reach (especially compared to the lower figures for hydrogen proposed by the author), as hydrogen must still be produced via electrolysis, and at the end electricity needs to be generated from ammonia to be supplied to the users, just like for the hydrogen supply chain. In addition, the energy consumption of the process needs to be considered.

In general, any proposed model needs to be reproducible, clearly describe the input data and the calculation procedures, to support a sound presentation of the results. Moreover, any result needs to include a description of the possible errors and approximations, by presenting a sensitivity analysis that highlights the possible variations. This is particularly true for complex energy systems, whose parameters show significant variations over time and in different world regions. All these aspects are missing in this manuscript, and thus I think that this research paper is not suitable for publication in its present form.

Another general comment to the framework: how about comparative advantage in generation and production + trade between countries? The introduced framework may be okay in a one-nation world with even distribution of RE potential. But if country A has significant comparative advantage for producing PV modules and generating electricity with PV and country B has a similar comparative advantage for wind turbines, then cumulative investment requirements are lower if country A targets investments in PV and country B targets investments in wind and they trade the produced electricity, rather than if both invest massively in PV (this is simply Ricardo’s comparative advantage).

There are other issues in the manuscript.

Although it is nice to see a paper written in an ‘entertaining’ language, sometimes the tone of the papers does not look suitable for a scientific publication. Moreover, there are several instances where important references are not cited:

- Section ‘Geopolitics of the black gold’ → at least cite an IPCC report when illustrating the link between energy consumption and climate change.
- Discussion on ‘The Dutch Disease’ → cite and critically discuss academic literature on the resource curse please

Page 4: “I propose that there is a direct positive relation...” → this is the core assumption of the paper and it should be better defended with some evidence, e.g. from the literature! I understand you later introduce a conceptual framework to back this assumption up, but the model is not validated or tested on real world data, so you could sketch a framework for any arbitrary assumption you wish to make. At least say ‘I hypothesise that’.

Page 4: “non-convex economies” : define what they are perhaps citing some literature, it is not obvious

Section ‘And green we go...’, line ‘(with exception of hydropower)’ → and biomass; also e.g. CSP

necessitates significant amounts of water.

Some charts are provided without numbers in axes (e.g. Figure 2), and the sources are not always properly referred to. In particular in Figure 2 the author should either specify it is a sketch or put values of the axes. Also, even if it is a sketch, put a source. In current form, it is not acceptable from a scientific perspective. Also, I question the linearity of these "curves"! At least specify immediately that it is a sketched graph that neglects the declining returns (second derivative negative) to learning-by-doing.

Moreover, a fixed cost for fossil generation of 50 €/MWh appears rather approximated: there is in fact a range of costs depending on multiple variables, including a variation across fossil sources, including natural gas and coal (the latter being usually cheaper).

Also, below Figure 2: "Solar PV has a learning quotient of 23%, intercepting fossil fuel line (price parity) with a future cumulative quantity (power deployed) at over 1000 TWh" à future when and where?!

In some cases, limited examples are given that are not representing the complexity of the situation. In the section "Dangers of unbalancing the energy geopolitics". There are also countries that are actually decreasing their carbon footprint. The example of the US is important, but additional figures from other countries may help to have a broader perspective. While it depends on producer vs. consumer perspective, it is still a false statement for the EU (see https://ec.europa.eu/eurostat/statistics-explained/images/3/35/CO2_emissions_%E2%80%9494_production_and_consumption_perspective%2C_EU-28%2C_2008-2015_%28index_2008_%3D_100%29.png)

Section "Energy Streams": this section reports a limited perspective. It is true that energy cannot be created or destroyed, as stated by the first principle of thermodynamics. However, the second principle states also that the quality of energy always decreases, due to the increase of entropy, as in real world energy conversions are non-reversible. Without considering those aspects, this discussion is misleading.

Section "Downstream": the author states "We shall therefore not account for the transportation sector in this research as it will shape and adapt by itself according to the external environment and clients' needs". This sentence is very hard to justify, since the EV market is currently heavily pushed by environmental policies and public incentives. The author also states that transport "will be the strongest growing energy demand sector in the future". Thus, overlooking it seems not a satisfactory choice. The authors should also discuss the possible limitations on shifting towards electricity for specific applications, such as buildings heating. While heat pumps are promising, they are not directly applicable in all contexts, and they may require a significant improvement of power networks' installed capacity, especially in some specific time frames.

There are other minor typos/errors. "concentrated solar PV" is a typo, as concentrated solar power is a different technology than photovoltaic (PV). Cumulative power deployed (describing Figure 2) cannot be expressed in TWh, which is a unit for energy and not for power.

Other typos/language issues:

- Page 3: "Not least, the impact to the environment for such amounts of fossil-fuel consumptions is well documented8–11 and accounts" à "Not least, the impact on the environment for such amounts of fossil-fuel consumption is well documented8–11 and is responsible for..."

- Page 4: “The randomization nature of the world’s natural resources distribution” à randomization is improper; I would say uneven distribution
- Page 4: “lacking 11 TWh of power generation that has been supplied by carbon fuels” à typo, should be 101 TWh
- Page 4: “The literature seam to point” à seems to point

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

No

Are sufficient details of methods and analysis provided to allow replication by others?

No

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

No

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Michel Noussan: energy technologies, energy policy; Giacomo Falchetta: energy economics, energy modelling

We confirm that we have read this submission and believe that we have an appropriate level of expertise to state that we do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 20 Jan 2021

Emiliano Finocchi, Temple University, Rome, Italy

Denigrating other people work is not a constructive way of doing a peer review. Contents could be discussed without the need for an offensive use of the language. This review seems to be written from a biased source and questions the integrity of the reviewer itself. When the reviewer refers to my paper as written in a “entertaining language”, I would like to underline that this paper is intended not only for the academics, but for practitioners too. Many definitions are written on purpose to help the non-academic reader. Down to content:

First, this is a **Theory-Building Research** (for more information on theory-building please consult: Lynham, Susan. (2002). *The General Method of Theory-Building Research in Applied Disciplines. Advances in Developing Human Resources*), and not an empirical study, where theories are built on other researchers' work following a rigorous scientific reasoning. The theoretical model (not a framework) I present should be tested with empirical data on a second study (including a sensitivity analyses), opening an opportunity rather than a flaw. Real data can support or not support the model, in either case, it can't question methodology.

To build the model, I have started from Shayegh et al work (Shayegh S, Sanchez DL, Caldeira K: *Evaluating relative benefits of different types of R&D for clean energy technologies*) and mathematically calculated my way through. Calculations can be found from page 5 to page 8. The figures (not sketches) are generic, based on previous studies, and having a scale attached to the axes would not change the result. Figure 2 in particular, is drawn from Shayegh et al work. Doubting this figure, means to doubt a published work and should not be mentioned in this review. Moreover, it's well written that the starting point which Figure 2 was drawn, is driven by Shayegh et al work. In my second version I will make this clearer. In fact, when the reviewer states on Figure 2 that "I question the linearity of these 'curves'" he is questioning the linearity of Shayegh et al work, not mine. It is clear that the reviewer did not spent time to read Shayegh et al work at all.

When the reviewer comments "Figure 2: 'Solar PV has a learning quotient of 23%, intercepting fossil fuel line (price parity) with a future cumulative quantity (power deployed) at over 1000 TWh' à future when and where?!" misses the entire point of what I am trying to support. When and where are not the questions I am answering. "How fast or how slow compared to", would be the correct question. The reviewer is asking questions I myself did not ask in the paper.

Moreover, the reviewer states that the model is not replicable, but it doesn't explain why (it doesn't help much).

When the reviewer states that "The selection of the 'most suitable technology' at page 18 seems not to be grounded by a scientific analysis but just based on a qualitative discussion" I rather question if the reviewer acknowledges that a qualitative analysis is indeed a scientific analysis.

When the reviewer refers to ammonia as "The efficiency of 72% is wrong" I may understand his doubts, as there is an error on that reference. The correct reference 50 is "Nayak-Luke, R., Bañares-Alcántara, R., & Wilkinson, I. (2018). "Green" ammonia: impact of renewable energy intermittency on plant sizing and levelized cost of ammonia. *Industrial & Engineering Chemistry Research*, 57(43), 14607-14616". Nayak-Luke et al work states green ammonia is achievable at 72%. This is a published work. If we shall question every published work without another publishable work that dismisses the previous one, why are we so busy to publish? Based on Nayak-Luke work, the reviewer is wrong. I will correct all references in my second version.

When the reviewer states "Section 'Geopolitics of the black gold' à at least cite an IPCC report" what it really means? What is "at least" for him? Are my sources not enough? Why? "At least" is not a constructive comment if it's not backed up.

The reviewer's comment on the Dutch Disease is not clear. I really did not understand, as it was a dismissible reference, not part of the main reasoning. He could have simply advised to remove the comment. I don't believe there is the need to remove it, I will keep it in my next version.

The reviewer's comment on non-convex economies is understandable. I will explain more

on the subject in my second version of the study.

In terms of competitiveness (Riccardo's comparative advantage), the study argues that if countries cooperate and basket all resources for a common technology, that technology will achieve competitiveness at a faster pace. Rather than building wind turbines in your country, use the resources to build solar PV in other countries in a cooperative context. This implies building power generation in a country and power usage in others. If the reviewer had focused on the paper, he would understand that the framework within which the model is built, does not consider political implications. I will make it explicit in the second version that the model foresees the collaboration of nations rather than competition among them. The entire aim of the paper is to push for cooperation and collaboration, and not to spike competitiveness. Riccardo's paper assumes winners and losers, in a competitive environment, which in my paper, I assume that in a global warming scenario, we all win, or we all lose.

When the reviewer states that "the second principle states also that the quality of energy always decreases, due to the increase of entropy, as in real world energy conversions are non-reversible. Without considering those aspects, this discussion is misleading." I don't see where is misleading. Maybe the reviewer could share with us how this is misleading. Section "downstream", as suggested by the reviewer, opens to another (or many), new studies. Nevertheless, the reviewer is correct, and I shall explicitly define the boundaries of the study. I will correct this aspect in the second version.

"Other type of language errors" section of the review will be amended as suggested in the second version of the paper.

Thank you

Competing Interests: No competing interests were disclosed.

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