## Climate Change Leadership – the case for Electrification

Per Ribbing

<table>
<thead>
<tr>
<th>BANK GRID</th>
<th>POWER GRID</th>
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<tbody>
<tr>
<td>banknote</td>
<td>kWh</td>
</tr>
<tr>
<td>(does mix)</td>
<td>(does mix)</td>
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<tr>
<td>MONEY</td>
<td>ELECTRICITY</td>
</tr>
<tr>
<td>(does not mix)</td>
<td>(does not mix)</td>
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Both banknotes and kWh:s are anonymous and interchangeable = No moral choice is possible to make.

In the case of money and electricity with GO:s an audit is performed = A moral choice is possible to make.
Climate Change Leadership –
the case for Electrification

Per Ribbing

Licentiate Thesis
Division of Electricity
Department of Engineering Sciences
Uppsala, April 2019
Abstract

This licentiate thesis presents a new way of understanding Electric Power. The new perspective on Electric Power highlights the similarities between our banking system and our power system. The two different systems share a common abstraction. In the case of the banking system this abstraction is fully accepted. In the case of the power system this abstraction is not yet fully accepted. This thesis aims to clarify this abstraction and show the parallelism between the two systems and the two abstractions.

This thesis examines what the Product Electricity really is. What is it, in reality, we sign a power contract to buy and pay for, and how is this product transferred to us? This new understanding challenges the old, physical understanding of Electric Power. Understanding the similarity between our banking system and our power system becomes important when we examine our Power Markets, and it becomes absolutely vital to understand for those investing in new power generation.

In no way does this new understanding of Electric Power question or challenge the physics behind power generation and power transfer. Maxwell’s equations holds true. The laws of Ohm and Kirchhoff are still the laws by which the electrical and power system engineers must abide. But when it comes to the Product Electricity, the product traded on our Power Markets, the product that we sign power contracts to buy and pay for, there is a major difference. The new understanding challenges the old quite dramatically. It does in fact show that the old, physical perspective on the Product Electricity is flawed and has been a misconception for over a century. My primary goal in this thesis is to thoroughly explain the new perspective and by so doing clarify and dissolve the old misconception of what the Product Electricity actually is.

The scientific theory of the Greenhouse Effect now has over 195 years of published peer-reviewed science.\[1\] The threat of accelerating Climate Change is a scientifically solid fact. The Paris agreement must be met. My second goal with this thesis is to make credible that an electrification of our society is a possible and viable option. The possibility of a swift energy transition from fossil fuels to renewable electricity is made more likely, and more viable, thanks to the new understanding of what Electric Power really is, because now we have the de facto choice of not consuming any fossil power.

© Per Ribbing, April 2019
To Ebba, Gustaf, Safi & Elise;
I want to give you a world in peace.
But that won’t be, until it’s fossil free.
And that, dear reader, is the task for you and me.
**List of Papers**

This licentiate thesis is based on the following papers, which are referred to in the text by their Roman numerals.


II. **Per Ribbing, Mats Leijon**: “Historic Perspective on the analogy between the Electric Grid and our Banking System. Explaining the New Paradigm on Electric Power.” Submitted to *Nature Energy, March 2019*
**Contents**

1. Introduction ................................................................................................................. 1
2. Theory .......................................................................................................................... 3
3. Alternatives to fossil power .......................................................................................... 6
4. Climate science .............................................................................................................. 9
5. Solutions; Renewable power generation ...................................................................... 11
6. Solutions; Energy storage and Power regulation ......................................................... 19
7. Solutions; Electricity for transportation ....................................................................... 21
8. Discussion ..................................................................................................................... 32
9. Earth and mankind; Sustainable development ............................................................. 34
10. Summary of Papers .................................................................................................... 36
11. Svensk sammanfattning .............................................................................................. 37
12. Acknowledgements ...................................................................................................... 39
13. References .................................................................................................................. 40

Paper I

Paper II
1. Introduction

1.1 Background

The Swedish power market was deregulated 1996.01.01. The very same day the Swedish chapter of the IUCN: Swedish Society for Nature Conservation (SSNC) released, to the power market, their Ecolabelling of Electricity; Bra Miljöval El (Good Environmental Choice Electricity)[2]. Strictly speaking: Ecolabeled Power Contracts. The idea was sprung from the then Vice Chair of SSNC, now professor at Chalmers Institute of Technology and member of the Royal Swedish Academy of Engineering Sciences; Dr Tomas Kåberger[3]. I applaud such a visionary idea.

Since 1996 there has been an ongoing debate in many diverse arenas, in Sweden and elsewhere, concerning ‘Consumer Power’ on the Power Market. The debate has been misguided from the very beginning since it states, as an unquestionable truth, that all power mixes on the grid. This thesis will present a new understanding of what the Product Electricity really is, and actually has been for over a century. It will also examine the possibility of ‘Consumer Power’ as a possible force for a transition away from fossil to renewable sources of energy.

After now over 20 years of tiresome debate and ridicule, this tool for a sustainable transformation of the Nordic Power System will be thoroughly examined and explained. If accepted and widely spread it will have the potential to effectively transform and decarbonize the whole electric power sector. First the deregulated Nordpool power market, then the deregulated power markets in Europe, then all power markets world-wide. Only the deregulated markets, of course. The consumers must have the possibility of a choice of what power to buy. ‘Consumer Power’ is only present if there is a choice of what product to buy.[4]

1.2 The basic foundation of ‘Consumer Power’ on the Power Market

i) Arguments pro Consumer Power has been along the line: If everyone decides to choose to buy Green Power – then eventually everyone will have Green Power in their outlets (sockets).

ii) Arguments against Green Power has been along the line: Since electricity is mixed on the grid you don’t get what you pay for. Hence, marketing and sales of Green Power is a hoax[1].

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1 Claes Göran Kjellander, Dagens Nyheter 1996-01-17 “Konsten att tjäna gröna kronor”
However, since August 13th 2018 when the article: “On the Analogy Between the Electric Grid and Our Banking System: Investigating “Consumer Power” in Deregulated Power Markets”[5] was published in the International Journal of Earth and Environmental Sciences (IJEES-154, Open Access) it is obvious that the second argument is wrong. It is an argument from the old, flawed, physical perspective. It is also obvious that the first argument, however correct, is much too weak and a stronger, more confident, argument pro ‘Consumer Power’ is found in this statement:

iii) Consumers can choose not to have coal power in their outlets. They can say no to coal. Consumers can choose to not consume any coal power.

When consumers start choosing to not buy coal power anymore the interesting question arises: What electric power production will replace the fossil power no longer produced? Since there’s no longer anyone paying for it to be produced, production of fossil power will cease to exist. Fossil power will be no more.
2. Theory

2.1 Parallelism between Bank System and Power System

For there to be any ‘Consumer Power’ possible there must be a possibility of a de facto choice. The de facto choice is seen in this simple four-square already published in articles I and II. Below, I will elaborate on the parallelism between our bank system and our electric power system and further explain the de facto choice of not consuming any fossil power.

![Four-square over the parallelism between bank system and power system](image)

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2.2 The power stability parallel
The task of power regulation, keeping the grid stable at 50 Hz, is parallel to having all ATMs stacked full with banknotes to allow large, sudden withdrawals anywhere, any time of day, 7 days a week.

Nota Bene: kWh are mixed, banknotes are mixed. They are both anonymous and interchangeable.

Fig. 2 The power stability parallel

2.3 The energy storage parallel

Energy can be stored. Power cannot be stored. These are fundamental facts of physics that need to be understood. Energy with a potential to be converted into electricity can be stored. How then is ‘Green Power’ stored? The answer is: Guarantees of Origin can be stored. For each kWh produced, one (1) GO is awarded the producing power company (utility). These GOs are then saved in customers’ accounts and are cancelled (nullified) only after the customer has consumed one (1) kWh. That way ‘Green Power’ is stored; in GO accounts. The REDISS system in European Union guarantees that you get exactly the power you buy and no other. REDISS = Reliable Disclosure of Electricity Production.

If you don’t like coal power you have the de facto choice of not consuming any Product Electricity produced from coal. Just choose a Product Electricity that does not contain any coal power.
2.4 Examples of energy storage and power regulation solutions

Storing energy can be done in many ways, see A to Ω in chapter 5: “Solutions; Energy storage and Power regulation”. There, a full Greek alphabet of solutions for both power regulation and energy storage is presented. Here; a shorter version; (HBF)².

- Hydropower dams
- Hydrogen gas
- Biogas GCC
- Batteries
- Fuels (preferably solar fuels like e.g. CH₄, C₂H₆, CH₃OH, C₂H₅OH)
- Fuel cells (for power production)
3. Alternatives to fossil power

This thesis will briefly describe 6 possible alternative, renewable solutions as answers to that question:

0. Energy Efficiency = less electric energy wasted into heat (NWh)
1. Solar Power; Small scale and utility scale
2. Hydro Power; Pumped hydro
3. Wind Power; Offshore and on land
4. Wave Power; different technologies exists
5. Marine Current Power; Streaming and Tidal

Nuclear power is another non-fossil option but recent studies show that new traditional nuclear power (fission) is significantly more expensive than new wind and solar PV power. See e.g. Lazard LCOE 2017\(^6\).

![Renewable Energy — Historical Cost Decline](image)

Fig. 4 Lazard, LCOE: Levelized Cost Of Energy, 2017

Chances for an expansion of the market for nuclear reactors in the Western world appears slim. The last reactors probably to be built in Europe (Hinkley Point C, England) was commissioned in 2013 with a subsidized price of 92,50 GBP/MWh resulting in a power price of roughly 10 Eurocents per kWh. With new solar PV power and offshore wind power being commissioned at around half that price and land based wind power at around 4 Eurocents per kWh my conclusion is that the market for new nuclear reactors, most probably, is dead. Research and development can be seen in what is called Generation IV of the nuclear power
technology. Generation IV could possibly have the potential of using old spent nuclear fuel (nuclear waste) as fuel in its generation process. However, it is not as easy as some may think. The industrial development of Generation IV is highly uncertain, both from an economic and political point of view. In a deregulated market, who would want to invest capital in nuclear power production? China could, maybe, be a future market for Generation IV reactors and then (in a perfectly peaceful and all trusting world) EU, USA and the rest of the world could supply the Chinese Generation IV reactors with old nuclear waste since we, still today, have no definite decided solution (waste depository or other) in any country, for the handling of the nuclear waste we have produced since the 1950’s and on.[7] From Petr Ocelík et al we learn that “Even though the siting process has now been running for more than 20 years, no substantial progress has been achieved. On the contrary, the mobilization against the project have intensified after the list of pre-selected localities was published in 2003, and then again in 2014, after the geological exploration licenses were awarded (see Đurđović et al. (2014)). The closing deadline for the identification of the two pre-final destinations set on 2020 is further polarizing the debate between the investor (i.e. the state) and the local communities.”

In Sweden, as internationally, the nuclear waste problem remains unsolved. On January 23rd 2018, both the Swedish Land and Environmental Court and the regulatory agency dealing with the nuclear industry, the Swedish Radiation Safety Authority (SSM), submitted their reports to the government regarding the Swedish Nuclear Fuel and Waste Management Company’s (SKB’s) application to build a “final” storage facility for spent fuel, at Forsmark in the Municipality of Östhammar. The municipality had planned to hold a local referendum on the issue but cancelled it after the Swedish Land and Environmental Court recommended against approving SKB’s application. The final decision is now in the hands of the Swedish government, but the local referendum has been cancelled.[8]

Future will show whether Hinkley Point C will be online before or after the (probably last) Finnish reactor Olkiluoto 3 which was scheduled to go online in 2009 (construction started 2006) but is still, at this moment, not in production. Latest word is that it will not even go online this year, 2019, already a decade delayed.[9]

Hinkley Point C is scheduled to go online 2025, 12 years after it was commissioned. This means it will at best take 12 years to get another 2 600 MW nuclear generation capacity. That is time we don’t have for decarbonizing the power sector if we are to meet the targets agreed upon in the Paris agreement.[10]

During the last 12 years installed wind power has increased by 465 166 MW[2]. Only in the year 2017 there was 52 552 MW new wind power capacity installed.[3] During that same time (2006-2017) there has been a decrease in global nuclear power production.

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The Finnish nuclear reactor number 6, planned to be built by Rosatom in Pyhäjoki, will most probably not be constructed. Qui vivra verra.
4. Climate science

4.1 The Greenhouse Effect

The scientific article “Remarques générales sur les températures du globe terrestre et des espaces planétaires” (General remarks on the temperatures of the Earth globe and the planetary spaces) was published 1824 by the famous mathematician Joseph Fourier, most famous for the Fourier-series.\(^4\) Fourier based his idea on the so called “hot box” earlier constructed by Horace Bénédict de Saussure from Switzerland.\(^5\) Later Fourier published the article “Memoire sur les temperatures du globe terrestre et des espaces planétaires” in the Memoirs of the French Academy in the year 1827. Notably, the scientific history of Climate Change is based on published science from 1824 and on into present time. All the time the Scientific Method, with articles published only after peer-review, has been followed. This makes the scientific theory of the Greenhouse Effect 195 years, and counting. And never has the scientific theory of the Greenhouse Effect been proven wrong. Nonetheless, some people keep denying this very old and very well published science. The English language recently received a new word: ‘Climate Denier’ in 2017\(^6\) to define this group of deniers of published science. From the Oxford dictionaries: “A person who rejects the proposition that climate change caused by human activity is occurring.”

Quoting from the American Institute of Physics history of climate change page the article “Why we know about the greenhouse gas effect” by David Wogan\(^7\):

“How does the Earth’s blanket of air impede the outgoing heat radiation? Fourier tried to explain his insight by comparing the Earth with its covering of air to a box with a glass cover. That was a well-known experiment — the box’s interior warms up when sunlight enters while the heat cannot escape. This was an over simple explanation, for it is quite different physics that keeps heat inside an actual glass box, or similarly in a greenhouse. (As Fourier knew, the main effect of the glass is to keep the air, heated by contact with sun-warmed surfaces, from wafting away. The glass does also keep heat radiation from escaping, but that’s less important.) Nevertheless, people took up his analogy and trapping of heat by the atmosphere eventually came to be called “the Greenhouse Effect”.

This scientific theory was developed into a more correct understanding by the Swiss physicist Claude Pouillet who published “Mémoire sur la chaleur solaire, sur les pouvoirs rayonnants et absorbants de l’air atmosphérique, et sur la température de l’espace” in the journal “Comptes rendus des Séances de l’Academie de Sciences” 9\(^{th}\) July 1838.

In 1859 John Tyndall proved that carbon dioxide (CO\(_2\)) was a Greenhouse gas (GHG). He published his article “On the absorption and radiation of heat by gases and vapours, and on the physical connexion of radiation, absorption, and conduction,” in Philosophical Magazine 22 in the year 1861.

Maybe the most well-known article about the possible effects of the Greenhouse Effect was published by the Swedish Nobel Laureate in Chemistry; Svante Arrhenius. In the article “On

\(^{4}\) http://www.newworldencyclopedia.org/entry/Joseph_Fourier

\(^{5}\) https://jancovici.com/en/climate-change/scientists/since-when-do-scientists-know-for-climate-change/

\(^{6}\) https://en.oxforddictionaries.com/definition/climate_denier

the Influence of Carbonic Acid in the Air upon the Temperature of the Ground” published in Philosophical Magazine and Journal of Science, Series 5, Volume 41, April 1896, pages 237-276, Arrhenius stated that if the concentration of CO₂ in our atmosphere would double – then the global mean temperature would increase 4 °C. IPCC is now predicting a temperature rise in exactly this region: 2-6 °C. We are already at +1 °C.\[^{[11]}\]
5. Solutions; Renewable power generation

5.0 Increased Energy Efficiency

The NWh – the Nega-Watt-hour – is by far the cheapest source of energy. It is also considered the kWh with the lowest environmental impact. In the Nordic region we still use a large amount of the finest form of energy – Electricity (electric power has an Exergy value of 100 %) – to create heat at room temperature. Since 20°C air has an Exergy value of ≈ 7 %, when compared to an outdoor temperature of 0°C, we create an unsurpassed waste of around 93 % of the Exergy value in the consumed power.

\[
\text{Carnot Efficiency } \equiv 1 - \frac{T_c}{T_h} \quad (T = \text{temperature, } c = \text{cold, } h = \text{hot}) \\
\text{At room temperature } (T_h = 20°C) \text{ and with an outdoor temperature of } 0°C (T_c) \quad (8)
\]

this equals: \( 1 - \left( \frac{273,15}{293,15} \right) = 0,0682 \approx 7 \%

Professor Amory Lovins, founder of the Rocky Mountain Institute (RMI) and a distinguished expert in sustainability has described it as such:

“\textit{Heating a house with electricity is like cutting butter with a chainsaw. It’s inelegant, expensive, messy and dangerous.”}

A picture as vivid as it’s true. Electricity should be used in heat pumps with a COP-value of today; 4, or sometimes even higher. COP = Coefficient Of Performance(9).

5.1 Solar Power; utility scale and small scale

Today large (utility scale) solar PV power projects are booming(10).

1. Noor Complex Solar Power Plant, Morocco(11) 580 MW Completed: Late 2018
3. Longyangxia Dam Solar Park, China(13) 850 MW Completed: Mid 2015
4. Kurnool Ultra Mega Solar Park, India(14) 1000 MW Completed: July 2017

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*8 0°C = 273,15 Kelvin
*13 https://en.wikipedia.org/wiki/Longyangxia_Dam
*15 http://www.sunpowereddreams.com/the-largest-solar-power-plant/
Datong Solar Power Top Runner Base is under construction to become the world’s largest with then a total of 3 000 MW (3 GW) of installed PV power.

Parallel to this development in utility scale solar there is the boom in small scale home-owner’s solar PV. My own housing cooperative is just right now (spring of 2019) putting up 107 kWp solar PV with an estimated annual production of 91 000 kWh.

Fig. 8 Solar Power installation sketch, BRF Särstahem

5.2 Hydro Power; Pumped Hydro

An old and well-known technical solution is to use the excess of power production capacity at night, when power demand is low, to pump water back up to the dam where the pumped water is stored as potential energy, later to be converted back into electric power. Lately a new version; wind powered pumped hydro, has been tested in Germany, near the small village of Münster, near Gaildorf.

YOUR WIND FARM CAN DO MORE THAN YOU THINK...
Fig. 9 a, b, c, d, e – Wind powered pumped hydro in Gaildorf, Germany

5.3 Wind Power; Offshore and on land, HAWT and VAWT

The growth of large installations of wind power is still exponential, world-wide. Prices of offshore projects have declined further and recently (March 2018) Swedish state-owned power company Vattenfall, won the bid for the world’s first zero-subsidy offshore wind farm.
Through their Dutch subsidiary Nuon they won the bid to install and operate the 700 MW offshore wind farm “Hollandse Kust Zuid” in the Dutch North Sea.\(^{[19]}\)

![Global cumulative installed wind power capacity 2001-2017](chart.png)

**Fig. 10** Global cumulative installed wind power capacity 2001-2017

A new 12 MW Wind Turbine Generator (WTG), the first ever two-digit multi-megawatt WTG, with a capacity factor \(C_p\) of 63 % will be built during 2019 in the harbour of Rotterdam\(^{[20]}\). One (1) Haliade-X is said to produce 67 GWh of electricity annually. Further research and evaluation of actual production will reveal the most important factor; the EROI-value (Energy Return On Invested energy). Modern WTGs have EROI-values around 50.\(^{[12]}\)

5.4 Wave Power; different technologies are competing for economic success

Wave power is not a new form of renewable power generation. Different research and demonstration projects have for decades been trying to make it to market but not yet succeed. Recently the Uppsala University spin-off; Seabased, has tried to launch a wave power park on the Swedish west coast at Sotenäs, outside Smögen. Unfortunately, technological development has not yet produced a viable technology that holds steady over time. The ocean is a fierce opponent. More times than could be expected the forces of Mother Nature rips technology apart. The future of the Seabased project on the Swedish west coast is unclear but a number of international deals has been closed. A new Swedish wave power company “CorPower” has recently completed its Stage 3 Demonstration outside the Orkney island, Scotland \(^{[21]}\). The challenge now is not only the forces of Mother Nature but the drop in price of electricity from new offshore wind farms.


5.5 Marine Current Power, both Streaming and Tidal

Both wind power and wave power are intermittent energy sources. Current power, not yet fully commercialized, is not. Subsequently, current power has an advantage over all other forms of renewable power production: it is stable and secure and could potentially be a supplier of so called “baseload power”. It does not vary over time, at least not a lot. If the currents used are tidal currents then current power will only produce during certain hours of the day. Another spin-off from Uppsala University and developed from professor Mats Leijon’s invention “the Turbinator” is the company Current Power AB.

A “turbinator” is a turbine and generator jointly constructed to produce power.
The first pilot current power vertical axis generator in Söderfors is currently in operation as a research facility.

Fig. 14 Installing the first pilot generator at Söderfors, in river Dal (Dalälven).

The VACT (Vertical Axis Current Turbine) concludes the chapter on new power generation. We have just briefly touched upon 6 different solutions with the common denominator; Free Flowing Renewable Energy = Imported Exergy from outside the System Earth:

0. Energy Efficiency (NWh)
1. Solar Power
2. Hydro Power
3. Wind Power
4. Wave Power
5. Marine Current Power

A sustainable development of the global energy system means a lot more new electric power generation is needed. But the renewable energy resource is simply gigantic: [13]
Fig. 15 From Greenpeace Energy(R)evolution. Source: WBGU – German Advisory Council on Global Change (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen - WBGU)
6. Solutions; Energy storage and Power regulation

With the new paradigm on electric power properly in play the demand for renewable power will most likely increase. Since an increased dependency on intermittent power, mainly wind and solar, increases the demands on the power system’s ability to regulate large variations in power production this thesis will also describe some possible solutions for this engineering task; short-term and long-term regulation and balancing of the Nordic power system (or any power system for that matter).

Examining the parallelism between the bank system and the power system:

- to keep all the ATMs, everywhere in the system, properly stacked with banknotes and the connected bank accounts filled with money, allowing large and sudden withdrawals any time of day, every day of the week, all year round, is equal to the task of keeping the grid stable at 50 Hz and having large amounts of energy stored to tackle the intermittent energy supply from renewable free-flowing energy, e.g. solar and wind power.

There are more possible technical solutions to this task than the ones I choose to name here, and probably more new solutions will be invented. Engineers love to solve problems. Here is my A to Ω of possible technologies to balance intermittent solar, wave and wind, with some examples already on the market/IRL with their URL:
A – Aggregators www.sust.se/projekt/vaxel/
B – Bi-directional DC/DC Energy Hubs www.ferroamp.com
Γ – GCC on Biogas (Bio Methane) (Gas Combined Cycle)
Δ – Demand Side Management
E – Ethanol and other Solar Fuels
Ζ – Zink Oxide Batteries
H – H₂ Energy Storage www.vatgas.se
Θ – Thermal Energy Storage www.jointrine.com
I – Invest in Solar: www.jointrine.com
K – Curtailment of Solar power “Inverters act as the brain of the PV system”
Λ – Li-ion batteries www.northvolt.com
N – Na-ion batteries
Ξ – Xenofobia - is not a solution. We are all one. Earth is our only home. See Ψ. Closely linked.
Ο – O₂ Energy Storage[14]
Π – Pumped Hydro Energy Storage e.g. Pumped Hydro by Wind (chapter 4.2)
Ρ – Rotating Mass (in existing Hydropower + both Wind power and Current power)
Σ – Salt Energy Storage www.saltxtechnology.com
Τ – Tidal Power www.minesto.com
Υ – Yotta Joule (YJ). The annual amount of Solar energy received to Earth is 2,8 YJ
Χ – X-Makani, the power producing kite. www.x.company/projects/makani
Ψ – Psychology. Climate Denial needs to be addressed! See Ξ. Closely linked.
Ω = Ohm = Resistance.

The only reason to fail will be public and political resistance to a sustainable development. We will only fail if we choose to fail.

The dynamic functionality of the market economy will choose what solutions are most efficient from a market point of view. This is a fundamental principle of the market economy.

6.1 Solar energy potential

From the Colorado School of Mines lecture on Solar Energy:


The annual potential of solar energy is:

\[ 89 \text{ PW} \times 8766 \text{ h} \times 3600 \text{ s} = 2,809 \times 10^{24} \text{ Ws} = 2,8 \text{ YJ}. \]

The total global annual use of energy is 0,000576 YJ. See chapter 7: Discussion.
Solutions for the power sector, as described above, are abundant. The market will choose the most economical solutions. However, to solve the Climate Change challenge, we need to do more than just decarbonize power production. Many other areas need to leave fossil fuels. Production of heat and power is only 25% of the total emissions of CO₂, globally. Emissions are ~40 Gton/year, including AFOLU the emissions are ~50 Gton/year\[16\]. AFOLU = Agriculture, Forestry and Other Land Use.
Fossil fuels are also used in the transportation sector.

Fig. 17 GHG emission by economic sector. Figure SPM.2 in IPCC Summary for Policymakers 2018

I choose here very briefly to present solutions for the transportation sector, since electrification – with renewable power – could possibly be a sustainable solution when executing Climate Change Leadership. For a scientific solid definition of ‘Sustainable Society’ see FSSD; Framework for Strategic Sustainable Development in e.g. Journal of Cleaner
Production, volume 140, January 2017. The whole volume is focused on Strategic Sustainable Development.

When we are sustainable, we do not systematically contribute to...

- increasing concentrations of matter from the Earth’s crust
- increasing concentrations of substances produced by society
- degradation by physical means

...and we have no structural obstacles to
- Health
- Influence
- Competence
- Impartiality
- Meaning-making

Fig. 18 Journal of Cleaner Production, Special Edition Strategic Sustainable Development
The first Sustainability Principle in FSSD (above) excludes burning fossil fuels (or uranium or thorium) from a sustainable society unless all CO2 or other waste products is returned to the lithosphere (the Earth’s crust). So called ‘Take-Make-Waste’ processes (linear processes) are the physical cause of the unsustainable development of the industrial era. The same principle addresses the discussion about batteries. Batteries contain metals. Metals come from the lithosphere. Sustainable solutions must be circular solutions. Not more metals can be leaked out from the recycling process than nature can re-mineralize. The first order principle for a sustainable society states that: “Concentrations of metals do not systematically increase in nature”.

Resource streams of all materials must therefore be circular, especially metals that are rare in the natural environment. This means that thorough recycling and reuse of batteries is a must. New battery factories must be designed to function with only old, used batteries as their resource. No virgin metals. If metals needs to be mined we have not yet reached a sustainable car production.

Another conclusion drawn straight from the Sustainability Principles is that the fewer cars we need to produce the more likely we are to succeed. Car-sharing (EV-sharing) is therefore a good step and a step that could easily be developed when cars become autonomous. In a sustainable future we could be car users, not car drivers. We wouldn’t be forced to be car owners. We could be buyers of a car-share service where an autonomous car comes to you, wherever you are, and drives you to wherever you want to be. A car user. And this service could very well be a part of a public transportation system. EVs could be cars, buses, scooters, bikes, trikes – all electric.

7.1 Electric Vehicles (EVs)

The Electric Motor is

- Energy efficient
- Quiet
- Emission free

The superior energy efficiency of the electric motor (around 90-94 %) and the fact that it has zero emissions and a much lower sound pollution makes it the ideal motor for all kinds of vehicles; cars, bikes, buses, lorries, scooters, tractors, trains and even airplanes.
Fig. 20 Energy efficiency of an Electric Motor. MUT = Motor Under Test (23)

Energy efficiency is the percentage of energy output as a result from an energy input. The quota \( P_{\text{in}}/P_{\text{out}} = \eta \) = energy efficiency of an electric motor. Energy is Power times Time, \( E=P \cdot t \).

With the new paradigm on power properly in place there is no truth to the myth about EVs running on coal. It’s just a uniformed myth sprung from the oil lobby’s toolbox. People that has bought an EV does not choose to charge it with coal power. That is an absurd accusation.

- Nota Bene: the de facto possibility of having a choice of what power to charge your EV with is only thanks to the new understanding of the Product Electricity, the understanding that you can choose not to consume any fossil power. This was not an existing choice in the old, physical, paradigm where all power was mixed on the grid. It isn’t. It never was, since a century back. Audited power does not mix. The kWh:s mix. The power which is audited, e.g. with Guarantees of Origin, does not. And remember; It’s not the currents of electrons that develop the energy system – it’s the currents of money.

Only in the very early beginning of the electrification of the Nordic nations was the Product Electricity and the kWh the exact same. “The kWh was the Product Electricity, and the Product Electricity was the kWh. The very same.” A quote from article II:

Another popular myth spreading across the news media as well as on social media is the one that EVs create a large amount of CO₂ emissions when produced. Already today (2019) large EV producers have addressed the problem and are running their production on Green Power, e.g. Tesla, Nissan, BMW and VW. See e.g. how VW declared that their ID-EV will be Carbon Neutral.

A recent study from the Swedish Think-Tank ‘Power Circle’ in cooperation with IVL shows clearly that a battery Electric Vehicle is a better choice for the climate.\(^{24}\)

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**Fig. 21 The VW EV ID-series**

The superior energy efficiency of the electric motor (around 90-94 %) and the fact that it has zero emissions and a much lower sound pollution makes it the ideal motor for all kinds of vehicles in our cities e.g. cars, bikes, buses, scooters, lorries.

### 7.1.1 Electric cars – BEV

The most common way to carry energy for the electric motor on board the electric car is in batteries – Battery Electric Vehicle (BEV). There are now so many different brands of BEVs I do not need to show they exist. The market is ready.

\(^{24}\) Video in Swedish: https://www.youtube.com/watch?v=w40dnd69waY&feature=youtu.be
7.1.2 Electric cars – FCEV

Another way to carry energy for the electric motor on board the electric car is in a fuel tank, e.g. Hydrogen gas (H₂) where the fuel is converted to electric power in a fuel cell – Fuel Cell Electric Vehicle (FCEV). There are other fuel cells than the ones running on H₂ but today there still are some ideas concerning a market for H₂-FCEV. I find that less likely because of the low total system energy efficiency, energy efficiency “well-to-wheel”.

Fig. 22 Energy Efficiency “Well-to-Wheel” comparison BEV vs FCEV

However, this does not mean H₂-FCEV for electric propulsion is a bad solution. It is less energy efficient but has an advantage when it comes to heavier vehicles, e.g. trains, trucks and long distance buses. Existing railways that today have engines running on diesel could easily switch over to H₂-FCEV trains. The cost of erecting power lines, cables and other constructions to supply the railway with electric power is then saved. An example is seen in figures 27, 28.
7.1.3 Electric buses, examples

Fig. 23 Scania Electric Bus  
Fig. 24 Volvo Electric Bus

7.1.4 Electric trucks, examples

Fig. 25 Scania Electric Truck  
Fig. 26 Volvo Electric Lorry

7.1.5 Fuel Cell Electric trains, example

Fig. 27 Alstom Coradia iLint, FCEV Train  
Fig. 28 Ballard Fuel Cell Train

7.1.6 Electric tractors, examples

Fig. 29 Fendt e100 Electric Tractor  
Fig. 30 John Deere Electric Tractor

7.2 Electric vessels
7.2.1 Electric ferries, examples

Fig. 31 For Sea, Tycho Brahe, Helsingborg-Helsingör

Fig. 32 Ampere Electric Ferry, Norway

7.2.2 Electric aircraft, examples

Fig. 33 The author at Bromma Airport 5th June, 2018
Pipistrel Alpha Electric, Slovenia. Estimated range: 180 km.
Fig. 34 ELISE – Electric Aviation in Sweden, developed at Chalmers University of Technology
Fig. 35 Swedish Start-up Electric Airplane Heart, under development
8. Discussion

8.1 Potential of renewable electric energy

There is an old saying:

“The energy that we receive from the sun in only 1 hours’ time equals the amount of energy used totally, globally, all people, all nations, during one whole year. 1 hour = 1 year."

Let us calculate if this still is correct.
The annual influx of solar energy is: \[89 \text{ PW} \times 8766 \text{ h} \times 3600 \text{ s} = 2,809 \times 10^{24} \text{ Ws} = 2,8 \text{ YJ}\]
The annual use of energy (all energy: electric, heat, fuels) was according to IEA, International Energy Agency, 13759 825 ktoe which equals 576 EJ (or 0,000576 YJ) in the year 2016.\[18\]
Since the relation 2,8 YJ / 0,000576 YJ = 4861 we conclude that in roughly 2 hours, Earth has received the same amount of energy as we use totally, globally, during 365 days \times 24 hours/day.
In 2 hours, Earth has received: \[89 \text{ PW} \times 2 \text{ h} \times 3600 \text{ s} = 640 800 \text{ PWs} = 640 800 \text{ PJ} = 641 \text{ EJ}.\]
641 > 576 - but the IEA figure is from 2016 and with an even larger global population it is fair to say that this upgraded statement holds true;

“The energy that we receive from the sun in only 2 hours’ time equals the amount of energy used totally, globally, all people, all nations, during one whole year. 2 hours = 1 year."

This renewable energy is given to us every year. For free. Distributed all over the globe as solar rays, blowing winds, heaving waves, hydro dams filled with rain, flowing streams and marine currents. The de facto possibility of actively choosing to consume only 100 % free-flowing renewable power, and choosing electric motors for the work needed (e.g. transportation), leads me to my conclusion, my most sincere recommendation.

8.2 Recommendation

In this thesis I have shown that:

I. We can choose what power we consume; e.g. 100 % free-flowing renewable. (ch. 2)
II. Renewable power is cheaper than fossil and nuclear power (chapter 3)
III. The electric motor is pollution free when powered by clean power. (chapter 7)
IV. Solutions with electric motors are already on the market. (chapter 7.1 - 7.2)
V. The potential of renewable energy is 4000-fold what we use today. (chapter 8.1)
VI. The production of ‘Green power’ and the regulation and storage needed for intermittent energy sources has many solutions that can be installed today. The technology exists. The market will choose the most efficient solutions. (chapter 6)
These 6 facts, in my view, results in the statement that this is a logically consistent, scientifically based and economically viable recommendation:

To act on the risks of accelerating and irreversible Climate Change we should leave fossil fuels as soon as possible and start preparing to stop using bio-fuels (except biogas) for energy purposes and instead focus on free-flowing renewable electric power to power our societies.

Nota Bene:
1. Hydro power is Solar Energy
2. Wind power is Solar Energy
3. Wave power is Solar Energy
4. Streaming current power is Solar Energy
5. Marine current power is Solar Energy
6. Solar Thermal power is Solar Energy
7. Solar Thermal heat is Solar Energy
8. Tidal power is Lunar Energy
9. Geothermal power is internal Tellus Energy

Using all these different forms of renewable energy, each and every one with a gigantic potential, are obvious solutions when looking at the System Earth from a position out in space and using the Sustainability Principles from FSSD.

We must understand that we, de facto, have a choice of not consuming any fossil power. At all. Today and all the time since the deregulation of the Swedish power market in 1996. We just must decide to not buy any fossil power and choose actively what power we buy; power with Guarantees of Origin.

What will happen if a large enough Consumer Power movement against fossil power is formed, is that large sums of money (investment capital) will shift; away from fossil energy and over to renewable energy sources. More and more fossil power plants will shut down or be converted to run on renewable fuels because a product not bought will not be produced. That is the law of Supply & Demand.
9. Earth and mankind; Sustainable development

Since Exergy is always consumed in every conversion of energy any closed system is inexorably going towards its own Entropy Death. That is the Law of Nature itself. But since planet Earth is an open system for energy (and exergy) Earth has developed into an inhabitable planet; a planet with Life. However, at the current rate we are destroying the life supporting systems. Not only the Climate. A famous article by professor Rockström et al “A safe operating space for humanity”, defined Planetary Boundaries already in 2009. Climate is but one of the threats to the human race. We are risking the very fabric of life, risking our own species to go extinct.

Fig. Planetary boundaries, Rockström et al

9.1 What is ‘Sustainable Development’?

First, one must understand what Sustainable Development means. Sustainable = Sustain Able = Able to Sustain. What is it that we must be able to sustain? What is it that we must be able to sustain? What is it that we want to be able to sustain? My answer is: To love. Children are the fruits of love. To sustain our ability to love means to sustain mankind to have the ability to bear children. If we do not change today’s development into a sustainable development there will be no more children, i.e. the human race will go extinct.
9.2 Personal endnote

I took part in the proper celebrations of my old family’s 700 year jubilee. I hope there will be a GRAND party in 2295 when the Ribbings of that era will celebrate our jubilee of a millennium. But that will not happen unless we start changing the present development into a sustainable development and in that process Green Power can play a very central part.

For the sake of my children, and for myself, I will continue my work of transforming our world into a sustainable world.

To Ebba, Gustaf, Safi and Elise; I want to give you a world in peace. But that won’t be until it’s fossil free - and that, dear reader, is the task for you and me.

/Sir Per Ribbing
10. Summary of papers

This thesis has two goals; to explain a new understanding of what Electric Power really is and that it is a sound and logically consistent, scientifically based and economically viable recommendation to say that we should leave fossil fuels as soon as possible and start preparing to stop using bio-fuels (except biogas) for energy purposes and instead focus on free-flowing renewable electric power to power our societies. This to, in the best and fastest way, meet the targets agreed upon in the UN Paris Agreement of December 12th 2015.

Paper I


This is the first scientific article that explains the new understanding of what Electric Power really is. It explains the de facto possibility of choosing not to consume any coal power. Take-home-quotes;

“In a deregulated market it is the currents of money that rule and develop the power system, not the currents of electrons. And:

“In the new paradigm the Product Electricity which is audited (electricity with GO:s) does not mix with the Product Electricity which is not audited (electricity without GO:s). Electricity with GO:s is traceable and a customer buying such a product receives that product, no other.”

Published in the International Journal of Earth and Environmental Sciences, 3: 154, 2018

Paper II

Historic Perspective on the analogy between the Electric Grid and our Banking System. Explaining the New Paradigm on Electric Power.

This second article explaining the new understanding of Electric Power as an economic entity uses the time of the early stage of electrification to show where the old misunderstanding that “all power mixes on the grid” originates from. In the city of Västerås the first hydro power turbine was installed already in the year 1891. At that time everyone in Västerås had ‘Green Power’ in their outlets. “The kWh was the Product Electricity, and the Product Electricity was the kWh. The very same.”

We have to move beyond that misunderstanding now. We must understand that we have a de facto choice of not consuming any fossil power. At all. Just don’t buy any fossil power. What will happen is that large sums of money (investment capital) will shift from fossil energy to renewable energy sources. And more and more fossil power plants will shut down because a product not bought will not be produced. That states the Law of Supply & Demand.

11. Svensk sammanfattning

"Det är inte strömmar av elektroner som utvecklar energisystemet. Det är strömmar av pengar."

Fortfarande, 23 år efter introduktionen av Bra Miljöval El, är den gängse uppfattningen att "all el blandas på nätet". Den här avhandlingen visar att det är en missuppfattning; el med ursprungsgarantier blandas inte med el som saknar ursprungsgarantier, dvs el som inte revideras.


  Sedeln är bara en anonym förmedlare av de pengar jag valt att tjäna.
- Vi har ett elnät. Där blandas kWh – men inte el.
  kWh är bara en anonym förmedlare av den el jag valt att köpa.


Parallellen med Elnätet
Du och jag står vid våra elektriska vattenkokare. Varsin vattenkokare har vi i våra respektive kök. Den första kW blir din el om du trycker före mig – men exakt samma kW blir min el om du låter mig trycka igång min vattenkokare först.

Vi vet att med den revision som sköts av nätbolagen och Energimyndigheten så kommer vi inte att få någon annans el. Vi kan enbart ta ut vår el från våra respektive kontakter. Att vi inte vet varifrån den kWh kommer som är den anonyma förmedlaren av vår el hemma i kontakterna är inte något problem. Det är en vardaglig abstraktion som vi nu har att förstå och fullt ut acceptera.

Det kan bli så att vi i våra kontakter hemma får en kWh som producerats i ett kolkraftverk. Det är inte något hållbart argument för oss att köpa kolkraft. Om alla slutade köpa kolkraft skulle inga kraftverk eldas med kol. Den el som ingen köper produceras inte.

Lagring av energi

"På elmarknaden är det inte Ohms och Kirchhoffs lagar som styr. På elmarknaden styr lagen om Tillgång och Efterfrågan."

2. Framtidens barn behöver fred och el. men freden försvinner om vi väljer fel EL.
12. Acknowledgements

First and foremost, I would like to thank my dear mother, Margit, for all support, especially during the difficult times that has passed since I, at the ripe age of 49, was accepted as a PhD student at the Department of Engineering Sciences, Division of Electricity, in May 2012 turning 50 just a month later.

Then, of course, thanks to all my children. Ebba; for being such a totally awesome wonderful person, Gustaf; for saving my life and being the wonderful, kind, loving, funny person you are. Elise; for being such a smart survivor and the sparkling joy of my heart. Extra thanks to Safi for helping me more than I can express. You are such a wonderful person, Safi. All of you are! I love all of you with all my heart. For trying to secure a future in peace for all my children I am committed to fight this fight to the very end.

Thanks to my supervisors, professor Mats Leijon and my assistant supervisor professor Hans Bernhoff, for letting me have this chance of changing the understanding of what Electric Power really is. I hope I have succeeded. Future will tell.

To all of my colleagues at the Division of Electricity I shout out a big “Thank you”! When times were at their darkest my friend Dr Kaspars Siliņš said a few encouraging words that I will carry with me for the rest of my life. Thank you! And thank you Dr Victor Mendoza for being such a great green support, and to all of you, my other colleagues at Vis Honorem. You are truly great people!

A warm note of gratitude to professor Karl-Henrik Robèrt for being the brains behind, and the founding father of; the NGO ‘The Natural Step’. The Framework for Strategic Sustainable Development (FSSD) is an ingenious piece of scientific clarity helping our societies transform. Thank you also for all personal help.

I would like to be one of the very first to publish a sincere note of gratitude and an official acknowledgement of the bravery and leadership shown by Greta Thunberg. She is a hero. In the future literature on Civil Disobedience she will be named alongside Dr Martin Luther King, Rosa Parks and president Nelson Mandela. Thank you Greta!

Now, please help me. The threat of Climate Change is more than serious. It is more serious than our society has yet been willing to accept and take in. And all the time the ‘Useful Idiots’ of the Coal- and Oil-lobby are actively denying published science. It is nothing but a disgrace.

In this fight for future peace I call upon your help. Thank you all!
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Abstract

This article investigates the Product Electricity, the product being sold at our power markets and distributed via our electric grids. The paper aims to enhance the understanding of the physics behind the Product Electricity. The traditional (physical) perspective of the purchase of power might have been compromised already in the early 1900's. This investigation aims to clarify what electric power really is, how it is traded, and if the different offers of so called 'Green Power' are valid.

A deregulated power market is ruled by the laws of the free-market, i.e. Supply and Demand. It is not ruled by the laws of Ohm and Kirchhoff. To purchase the Product Electricity is to place an order of consumption beforehand, not specified in volume, space or time. The economical transaction; purchasing electric power, is strictly non-physical.

Today, an active choice of not buying fossil power is advertised on the power markets. Customers who do not want to get electricity generated from fossil fuels are offered to stop buying it. This article tries to answer the question if that offer is valid.

Introduction

One form of energy, often converted from the burning of fossil fuels, is electric energy i.e. electricity. This paper takes a closer look at the Product Electricity in deregulated electricity markets. The deregulated electricity market in the Nordic countries + the Baltic states (Nord Pool) today offers the possibility of active choices by consumers; 'Consumer Power' if you like.

Global Warming as an adverse effect from burning of fossil fuels, described already by Svante Arrhenius in his 1896 article: "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground" [1], is now a global concern. Different labels of different kinds of electricity exists, not only in the Nordic countries but all over Europe and North America. However, quite a few questions have been raised, in media as well as in academic papers, over the possibility of separating different kinds of power (e.g. wave, wind, solar, hydro, bio or nuclear) and selling it (sending it) to specified customers.

Is that really possible?

To be able to answer that question we need to investigate the Product Electricity, the product being sold in our power markets and distributed in our electric grids. Doing so, an analogy with our banking system is investigated. The banking system is a system we know very well and use as often as our energy system, i.e. daily. In the banking system we separate the words "Money" and "Banknote" and handle them separately (Figure 1). Never did we question that the Banknotes we withdrew from our account was our money. We know that there is an audit made, an audit that would never allow us to withdraw more money from our account than we have deposited and we know that we could never withdraw any other person's money, only our own, previously deposited, money. This is clear. Even though we never, with any certainty, can tell from where the physical banknotes came.

Figure 1: The pedagogical foursquare (1st).

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Copyright: © 2018 Ribbing. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
However, how we view the Product Electricity is not clear. After studying almost 100 peer reviewed scientific articles a questionable level of understanding of what electric power really is, was detected. Therefore this article first states the fundamental physics of power production.

**Fundamental physics**

Electric power has to be consumed the very same instant it is produced, and vice versa. Electricity itself cannot be stored. However, it could be converted into chemical potential energy and stored in a battery, or it could be converted into hydrogen gas and stored in a H2 storage, e.g. Also, water can be stored in dams at hydropower stations, storing a potential energy later to be converted into electric power. This can be done by saving water in the hydropower dam by reducing the flow through the turbines. This is normally the case when e.g. wind power production is high. Or, water can also be stored at times of low demand, often at night, in so called pumped-storage hydropower. But electricity, in itself, cannot be stored. That's fundamental physics, not commonly known by the majority of power consumers.

Power production must, at all times, be equal to power consumption:

\[ \sum P = 0 \quad (P_{\text{produced}} - P_{\text{consumed}} = 0) \quad (1) \]

This follows both from the first law of Thermodynamics (Equation 2) and Kirchhoff’s Current Law (Equation 3).

\[ W_0 = W_1 \quad \text{Energy is always preserved} \quad (2) \]
\[ \sum I = 0 \quad \text{The sum of currents flowing into and out of a node always equal zero} \quad (3) \]

Electric power is an electromagnetic wave travelling at the speed of light through a conductor with free charges, in the normal case: electrons. The more free charges (electrons) there are the less resistance and therefore less heat loss, there is. The electric power is the electromagnetic wave. Not the electrons.

\[ P = V \cdot I \quad \text{Electric Power (P) equals the product of Voltage (V) and Current (I)} \quad (4) \]
\[ W_0 = P \cdot t \quad \text{Electric Energy (W_0) equals the product of Power (P) and time (t)} \quad (5) \]

The SI unit for electric energy is Joule (J): 1 J = 1 Ws, but electricity is bought and sold in kilowatt-hours (kWh) where 1 kWh = 3600 MJ. You cannot determine (downstream) how a specific kWh was produced (upstream), but you can **audit** how a kWh was produced (upstream).

**Energy storage and power regulation**

As Equations 1, 2 and 3 all state there must always, at every second, be a balance in the power system, a balance between power production and power consumption. A measure of imbalance between production and consumption is the grid frequency, \( f \) [Hz].

If power production > power consumption the grid frequency increases so that power production = power consumption (i.e. energy is stored as kinetic energy in the rotating mass of the generators in the system, hence they speed up).

If power production < power consumption the grid frequency decreases so that power production = power consumption (i.e. kinetic energy is released from the rotating mass of the generators in the system, hence they slow down).

\[ \text{If } P_{\text{produced}} > P_{\text{consumed}} \Rightarrow f \text{ increases until } P_{\text{produced}} = P_{\text{consumed}} \]
\[ \text{If } P_{\text{produced}} < P_{\text{consumed}} \Rightarrow f \text{ decreases until } P_{\text{produced}} = P_{\text{consumed}} \]

The grid frequency is monitored and kept within limits 49.90-50.10 Hz by Svenska Kraftnät (Swedish National Grid) at all times. Two fundamental parameters must be kept under close control; Power and Energy. The task of keeping the power balance: \( P_{\text{produced}} \cdot t_{\text{consumed}} = 0 \) (Equation 1) becomes slightly more difficult when more intermittent sources of energy is added to the system, e.g. solar PV and wind power. Both these sources are intermittent. Hence, the energy storage facilities in the system are crucial for a secure supply of power. Earlier studies has shown that the existing hydropower in Sweden has the capacity to regulate at least 11,000 MW (11 GW) of installed wind power [2] and that a 100 % renewable power system in Sweden is possible [3].

**Fundamental Economics**

It’s obvious that it is crucial to separate physics and economy in this matter. On a market the customer is king. A product that doesn’t find any buyers will not stay on the market. In a deregulated electricity market the customers are offered a choice of what kind of power they want to buy. Power that no one buys will not be produced. E.g. no one will burn coal in a coal power plant unless they are paid to do it.

**Different forms of electric power**

The Product Electricity comes in many different environmental qualities. Only one (1) kind of the Product Electricity on the Swedish market contains electricity generated from fossil fuels (coal, oil, gas) (Figure 2). That is the Nordic Residual Mix (NRM)1. NRM is unspecific electricity, so ceasing to buy unspecific electricity (electricity without Guarantees of Origin) is in fact a cessation of buying fossil power. How do we know this? Through auditing! NRM is electricity that is unspecific upstream. The other alternatives are not, because they are all audited and sold with their Guarantees of

![Figure 2: Fossil fuels in swedish power production.](image-url)
In fact, nowhere have I found any preferences to buy fossil power. This is also true in many other countries [6,7,8,22,23].

In Sweden, especially, consumers do not speak about the fact that we do have fossil fuels involved in Swedish power production1 (Table 1) [4].

Trading at Nord Pool

Besides Sweden all other countries (except Norway) trading electricity at the power exchange Nord Pool Spot, have a much larger share of fossil fuels in their electric power production.

If no one bought fossil electricity all fossil power plants would eventually have to be phased out. This conclusion can be drawn from a simple fundamental principle of economics: a product that no one buys, no one will produce. That’s just as true regarding electric power as any other product. The general confusion regards this specific question: How do I know I don’t get any fossil power? By auditing is the simple answer.

Auditing by the EU system: REDISS – Reliable Disclosure Systems for Europe

There still is a very low percentage of customers making an active choice when buying electric power, though declared preferences suggest otherwise. The reason for this could be the common misunderstanding concerning the purchase of the Product Electricity. The common misunderstanding states that “all power mixes on the grid, hence it’s impossible to choose what power you buy”. This common misunderstanding has even led the Norwegian Consumer Authority to rule marketing of “Green Power” illegal3 and the Nordic common misunderstanding has even led the Norwegian Consumer Authority to rule marketing of “Green Power” illegal3 and the Nordic Ecolabel to omit criteria concerning what power their licensees must produce from fossil fuels is something consumers definitely do demand. Actually, today, to a large extent, consumers already have this possibility but the general confusion over the physics of power production and distribution, coupled with very little knowledge of how the trading of electricity is done, has resulted in very few active choices of what electricity people buy. Also, there is very little knowledge about the EU auditing system; REDISS (http://www.reliable-disclosure.org/) where the audit of Guarantees of Origin (GO:s) ensure customers that double-selling of “Green Power” is impossible.

Definition of the economic entity: the Product Electricity

Buying electricity is quite different from purchasing any other product. Buying the Product Electricity is actually placing an order, beforehand, of kilowatt-hours to be produced. The annual purchased volume is estimated from last year’s consumption. The purchased electricity could be consumed at any time and at any geographical location where the consumer is identified and the consumed product is metered. To clarify, I use the case of charging an electric vehicle. An electric vehicle can be charged at many different geographical locations, any day and time of day. If the charged volume of kilowatt-hours is metered and the consumer is identified (e.g. starting the charging with an RFID-tag or Smartphone) then the purchased volume of the Product Electricity could be added to the identified consumer’s electricity bill. The consumer does not know how many kWh will be consumed during a year (how many electric kilometers will be driven). The Product Electricity is balanced over a year and there is a balancing done at the end of the year where the actual consumption is revised versus the anticipated and the difference is billed, or deducted, on the next bill.

Definition of the physical entity: the kilowatt-hour (kWh)

An electric vehicle can be charged with a number of different plugs and outlets, at different levels of power, some cars with both AC- and DC-charging. The consumer, of course, does not know which physical kilowatt-hours (upstream) are consumed during charging but the specified Product Electricity (downstream) comes with Guarantees of Origin that are cancelled in the same amount as the kilowatt-hours being charged. The REDISS auditing system guarantees traceability of the purchased Product Electricity. Hence, there is no risk of involuntarily charging your battery electric vehicle (BEV) with fossil power.

Historic explanation

Looking at the history of the development of a nationwide electric grid in Sweden can give an explanation as to why the traditional perspective of purchasing the Product Electricity is still perceived as valid. Scientific articles in this matter have been hard to find, see e.g. David L. Morton [9].

Table 1: Fossil fuels consumed in Swedish power production.

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal &amp; Coke</th>
<th>Petroleum products</th>
<th>Fossil Gas</th>
<th>Other (Waste)</th>
<th>Total (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>2864</td>
<td>2435</td>
<td>5097</td>
<td>1993</td>
<td>10396</td>
</tr>
<tr>
<td>2011</td>
<td>2555</td>
<td>1094</td>
<td>3493</td>
<td>1999</td>
<td>9141</td>
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<td>2012</td>
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<td>6588</td>
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<td>524</td>
<td>1481</td>
<td>1883</td>
<td>5406</td>
</tr>
</tbody>
</table>

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3https://www.forbrukertilsynet.no/english  
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6http://www.svanen.se/en/  
7http://www.forbrukertilsynet.no/english  
8https://www.ei.se/en/  
9https://www.ei.se/en/
Picture the case of a single generator, e.g. a hydropower station (A) in the early 1900’s, powering a local grid (α). In another location a similar hydropower station (B) powers another local grid (β). The consumed Product Electricity was in this original configuration the exact same as the physical kWh consumed. No audit was performed. It was not needed. Metering of consumed kWh:s was sufficient since the physical entity (the kWh) was identical to the economic entity (the Product Electricity). But as soon as the grids α and β were interconnected (α+β) there was no way of telling from which hydropower station the physical kWh the different customers received (downstream). Still, the metering of consumed kWh:s was the only data needed since the customers continued paying the power bill to the same power company (A or B) that the customer “belonged to”, meaning which grid they were getting their electricity from: grid α or grid β. The Swedish power grid developed into a nationwide power grid and then developed even further as the Swedish grid got connected to the grids of Denmark, Norway and Finland, and now, as of lately, to the power grids of the Baltic states. In Sweden the electricity market was regulated in geographical monopolies (grid monopolies) up until 1 January 1996 [10]. Before that date consumers could not make any active choice concerning what power to buy. During the monopoly the view of the Product Electricity was the physical one, where the currents of electricity “flows” and mixes like currents of water. This view of the Product Electricity stayed on even after the deregulation, and that view has unfortunately stuck with the majority of both consumers and producers. This paper aims to modernize this view and bring it into the 21st century.

REDISS, Auditing Consumption vs Production with Guarantees of Origin

The Swedish power grid is interconnected with the power grids of all our neighboring countries and the Nordic region is connected to the rest of Europe. In 2020, Norway will have a direct 1400 MW HVDC-connection to England [11]. The cable will run from Kvilldal, Suldal in Norway, to Bryth in the United Kingdom. The NSN Link (North Sea Network) will be a part of the North Seas Countries Offshore Grid Initiative (NSCOGI) which integrates offshore wind farms and other renewable energy sources across the northern seas of Europe. The Swedish NordBalt 700 MW HVDC, connecting Sweden and Lithuania, went on-line in the beginning of 2016 [5].

The power market is ruled by the normal laws of free-market economy; the laws of Supply and Demand [12]. The power market is not ruled by the laws of Ohm and Kirchhoff [13,14]. The electric grid, and the production and consumption of electric power, is ruled by the fundamental laws discovered by Georg Simon Ohm and Gustav Kirchhoff - but not the power market itself. It is absolutely crucial not to mix physics and economics to properly understand this new perspective, and the possibility it presents to help develop a fossil-free energy system.

In this paper I suggest that utilities, policy makers and society as a whole start using a new and different perspective on the Product Electricity, a strictly economical, non-physical perspective. Using this perspective, the market would open up possibilities for consumers, large and small, to effectively execute their ‘Consumer Power’ on the Nord Pool electricity market. I also make a suggestion to the European Union, to their REDISS system, below. This new economic perspective on the Product Electricity also reveals that consumers indeed do have the possibility to stop buying electric power generated from fossil fuels already today. Hence, the proposed new perspective gives the consumers the possibility to have an impact on the flows of (investment) capital. Of course, the consumers have no impact of the physical flows of the produced electromagnetic fields (this is self-evident [14]) but since it is the currents of money that develop the energy system and not the currents of electrons this is not a point to get stuck on. Now, obviously, the demand for an audit becomes inevitable. It mustn’t be possible for a utility to sell more of a specific Product Electricity than they have produced (or purchased from another producer). An audit to prevent “double-selling” must be performed. This is exactly what the EU-system REDISS does; Reliable Disclosure Systems for Europe. With the new perspective it is evident that the customers of an electric utility company have the opportunity to stop buying fossil power simply because the consumer can actually buy the specified power he or she wants.

The traditional perspective

The traditional perception of how electricity is purchased and consumed can be exemplified by quoting a large number of the reviewed papers, e.g. Hansla et al: [15]

“When supplied to a home it is not possible for the household consumer to know how the electricity was produced.”

How the historical view of electricity perceives the Product Electricity as something that is delivered (physically) can be described by quoting Hauch: [16]

“In Norway, CO₂ emissions can be reduced only by substitution in households and in other productions sectors than electricity.”

Actually, in Norway most of the Guarantees of Origin in the REDISS-system are sold abroad so that only 15 % of the “green value” is left in Norway [15]. The system of selling the “green attributes” (the Guarantees of Origin) separate from the Product Electricity creates a misunderstanding. The general public in Norway think they are consuming almost 100 % hydropower but they are actually consuming the Nordic Residual Mix (Figure 3) which contains both fossil electricity (42.77 %) and nuclear power (40.55 %). Only 16.68 % of the Nordic Residual Mix 2017 was renewable power [6]. This Residual Mix is calculated by the Swedish Energy Markets Inspectorate (www. el.se) each year after cancellation of the traded Guarantees of Origin.

The new perspective

Contrary to the traditional view I propose a different definition of the Product Electricity. The proposed definition of the Product Electricity is the specified product the customer chooses to buy, according to the contract with their utility. The physical delivery of said product is made by anonymous kilowatt-hours who are carriers of the value produced, the value not only being electric energy but also environmental values.

This suggested to the European Union, to their REDISS system, below: 8Suggestion: do not allow Guarantees of Origin to be sold separate from the power. The GO should never be separated from the Product Electricity sold as “green”. This way fossil power could never be sold (with acquired GO:s) under the false pretense of being “green” or anything else. This is possible today only because GO:s are allowed to be traded separate from the power itself.

11https://www.ei.se/sv/for-energiforetag/el/ursprungsmarkning-av-el/
12https://www.worldenergy.org/entry/Gustav_Kirchhoff
13http://global.britannica.com/biography/Georg-Simon-Ohm
14http://www.newworldencyclopedia.org/entry/Gustav_Kirchhoff
Methods

An extensive review of scientific articles covering the subject has been made. All of the studied articles have been written in the traditional, physical perspective as exemplified above, and below. The proposed new perspective on the Product Electricity in a deregulated market is presented and elaborated on.

The physical perspective

The traditional perspective on electricity as a product that cannot be traced applies for all consumers of the Product Electricity from a shared grid, big or small, public or private, homes or industries. Let the traditional perspective be named the “Physical Perspective”, where essentially currents of electricity are looked upon as currents of water, all being mixed on the electric grid. In the Physical Perspective this description by Wüstenhagen and Bilharz [17] holds true:

“Unlike in the case of buying organic food or other green products, a green power customer does not get a physically different product, but the difference lies in monetary flows. If products are designed properly - i.e. double-selling is avoided - the purchasing decisions of green customers will translate into a change in the electricity mix.”

However, in the new perspective, defined below, that description is a misconception.

When Swedish Society for Nature Conservation introduced criteria for Eco labeled electricity in January 1996 [18] articles in press and media, e.g. the largest Swedish newspaper, Dagens Nyheter, in for Eco labeled electricity in January 1996 [18] articles in press and media, e.g. the largest Swedish newspaper, Dagens Nyheter, in

to explain the new perspective an analogy is introduced; an analogy with a very well-known system that everyone uses practically every day; the Banking System: The banking system uses anonymous agents of money, e.g. banknotes, to transfer money from a client’s account to the client. In an Automatic Teller Machine (ATM) the banknote at the very top of the stack inside the machine can either be person A’s, if A precedes B in line, or B’s, if A lets B precede him. However, the fact that the banknote at the top of the stack can either become A’s or B’s (the banknote itself is interchangeable), does not make A’s and B’s money interchangeable. Hence, the banknote itself is an anonymous agent of the money in said persons account.

Nota bene: The word “money” is noted different from the word “banknote”.

In just the same manner the power system uses anonymous agents of the Product Electricity; e.g. kilowatt-hours (or Joules, 1 kWh = 3.6 MJ). If person A turns on his electric kettle before person B, A gets the first Joule waiting in line to be produced (and instantly consumed) from the electric grid while if person B turns on his electric kettle before person A, B gets that very same Joule. However, the fact that the next electric Joule produced (and instantly consumed) can either become A’s or B’s (the Joule itself is interchangeable) does not make A’s and B’s electricity interchangeable. Hence, the Joule (or kWh) itself is an anonymous agent of the Product Electricity bought by person A and person B and is measured and deducted from said persons individual “electricity account”.

Figure 3: Nordic Residual Mix 2017.

Figure 4: Mediterranean Residual Mix 2017.
Nota bene: The word "electricity" is noted different from the word "kWh".

In fact, the new perspective was valid even during the time of the old power monopoly because if the Physical Perspective had been correct the consumer could never have known what power plant their kWh came from, hence they would not have known which utility company they should have paid their electricity bill to. Consequently, the Physical Perspective appears inconsistent to apply in any deregulated market. According to the traditional logic of the Physical Perspective each power producer would need to supply their electricity in separate electric grids which of course would be practically and economically unfeasible.

The new perspective might be conceived as somewhat abstract but the analogy with banknotes and money aims at making this easy to understand and accept. It's a way of communicating with the public. Most people do not have the necessary knowledge in fundamental physics to understand why electric power must be produced and consumed at the same instant. As a parallel, people have very little knowledge in the production of banknotes. Still no one ever wonders if the banknotes they withdraw from their account is, in fact, their money. They know that it is their money, no matter what banknotes they physically receive in their hand. They know you can only withdraw from your account the very same money previously deposited there. Not any other money, just other banknotes. Hence, let this new perspective be called the Banking Paradigm.

Physical property of electric power and grid stability

One fundamental physical property of electric power is that power cannot be produced unless it is consumed at the same time, instantly. To keep a grid prompted with the possible production of electric power, with a stable frequency and voltage (e.g. 230 V, 50 Hz), and also allow large variations in consumption, is the engineering feat of the grid operators. It appears, in our proposed parallel with the banking system, equal to keeping all ATM’s stacked with enough banknotes to allow a large variation in withdrawals. Some hours there will be large withdrawals, some hours only small withdrawals, or even none at all. But there must always be a stack of banknotes in the ATM. That’s the analogy for grid stability. The cost for keeping the grid stable, which safeguards society from black-outs, is paid by the consumers. What extra costs might arise, if any, when old fossil power generators are replaced by new power plants, or energy efficiency is enhanced in the system, is hard to foresee. Future evaluation will be of great interest, not only from an economical point of view.

Different products, different kinds of electricity

The parallel between the Product Electricity and money, as well as the parallel between anonymous kWh and anonymous banknotes, explains that a person buying a specified kind of electricity receives that product, no other. The purchased electricity is delivered by anonymous agents, kilowatt-hours, who are deducted from the consumer’s individual “electricity account”. The European system for

\[
\text{See section 1.1.1. If } P_{\text{production}} < P_{\text{consumption}} \Rightarrow f \text{ decreases until } P_{\text{production}} = P_{\text{consumption}} \\
\text{and if } P_{\text{production}} > P_{\text{consumption}} \Rightarrow f \text{ increases until } P_{\text{production}} = P_{\text{consumption}}
\]
Reliable Disclosure (REDDISS) and its GOs (Guarantees of Origin) ensures the power consumers that they get the Product Electricity they buy and no other. The criteria can be as simple as "non-fossil electricity" not having any further environmental limitations. Criteria could also be technically specific such as "solar power", sold by e.g. Telge Energii14 or "nuclear power", sold by e.g. Vattenfall15 or possibly "wave power" or "wind power from a vertical axis wind turbine" allowing for consumer awareness or preference of a potential advantage for vertical axis wind turbines (VAWT) over conventional, horizontal axis wind turbines (HAWT) [19]. 'Consumer Power' could assist in developing a domestic VAWT industry if a utility decided to start selling this specified product; Vertical Wind Power, only produced by VAWT's. The Bank Parallel proposes that any specific kind of electricity is possible to sell as long as a regular audit is conducted, as is the case here with GOs being audited.

In the new paradigm, the act of purchasing electricity has evolved into the act of placing an order of consumption, beforehand, not specified in volume, space nor time, but specified in environmental quality i.e. what environmental impact does the chosen power production have. In parallel: one can withdraw money from one's account not knowing beforehand where, when and how much one withdraws. There is a difference in the balancing. The balancing of the bank account after a withdrawal in an ATM is immediate; the balancing of the bank account after a credit card has been used is monthly. The balancing of consumed electricity is annual or sometimes more frequent.

From an environmental point of view there is a substantial difference between Eco labeled electricity and electricity guaranteed of origin. This since the 3rd generation of criteria for Good Environmental Choice Electricity e.g. demands that the power company selling the Eco labeled (Good Environmental Choice) electricity must deposit money in a fund for energy efficiency project. Therefore, when buying Eco labeled electricity from a utility the consumer also supports money in a fund for energy efficiency project. Therefore, when buying Choice Electricity e.g. demands that the power company selling this since the 3rd generation of criteria for Good Environmental Choice Electricity (GEC) must deposit money in a fund for energy efficiency project. Therefore, when buying Choice Electricity e.g. demands that the power company selling this is monthly. The balancing of consumed electricity is annual or sometimes more frequent.

In the new paradigm the Product Electricity which is audited (electricity with GOs) can be traced, hence it does not mix, whereas electricity which is not audited (electricity without GOs) cannot be traced, hence it does mix. It is the demand for a regular audit, preferably by a third party, that allows the Product Electricity to be traced. The audit is performed by auditing the volume of kWh:s produced in a specified power plant complying with a set of criterion, e.g. a windmill, a wave power generator, nuclear reactor or hydro power station, versus the volume of kWh:s sold as specified electricity. Then electricity, electricity Auditing produced kWh:s versus consumed kWh:s permits the Product Electricity to be traceable. The GOs in the EU-system REDISS makes this auditing of electricity very straightforward.

The necessary audit

In the new paradigm all electricity which is audited (electricity with GOs) can be traced, hence it does not mix, whereas electricity which is not audited (electricity without GOs) cannot be traced, hence it does mix. It is the demand for a regular audit, preferably by a third party, that allows the Product Electricity to be traced. The audit is performed by auditing the volume of kWh:s produced in a specified power plant complying with a set of criterion, e.g. a windmill, a wave power generator, nuclear reactor or hydro power station, versus the volume of kWh:s sold as specified electricity, e.g. Eco labeled electricity. Auditing produced kWh:s versus consumed kWh:s permits the Product Electricity to be traceable. The GOs in the EU-system REDISS makes this auditing of electricity very straightforward.

The quote from Hauch [16]:

"In Norway, CO₂ emissions can be reduced only by substitution in households and in other production sectors than electricity" reveals the common misconception. Just because the power is produced in Norway does not mean it is consumed in Norway, by Norwegians. It can equally be sold to Swedes, Finns and Danes who buy Eco labeled power. In turn, the power produced in Sweden, Finland and Denmark is bought and consumed by the Norwegian customers. The only way for a Norwegian to get his power from renewable sources of energy, e.g. Norwegian hydro power, is by buying auctioned electricity with GOs, e.g. Eco labeled electricity. The Norwegian power consumers will, simply by buying Eco labeled power, or nuclear power, reduce their CO₂ emissions from a level of emissions of CO₂ corresponding to the Nordic Regional Mix down to zero or very close to zero [20, 21].

Very few people in Sweden want to buy electricity generated from fossil fuels such as coal, oil and gas. This is true also for other countries [22, 23]. In Hauch [16] it is stipulated that coal is successively replaced by natural (fossil) gas thus reducing the CO₂ emissions. If the new power, solar, hydro, wind, wave or nuclear power, can never receive any other Product Electricity. For this new paradigm to function there must be a regular audit of produced volume of kWhs in specified power plants, e.g. windmills, hydropower stations or nuclear reactors, versus consumed volume of kWh:s by the customers buying the specified kind of the Product Electricity. In the EU-system REDISS a Guarantee of Origin (GO) accompanies each kWh sold as specified electricity. These GOs are being used for auditing Eco labeled electricity. The same reasoning applies to all electricity guaranteed of origin, e.g. solar power, wind power, wave power, hydro power or nuclear power. Here, the same GOs are used for auditing.

www.reliable-disclosure.org/).

In the new paradigm the Product Electricity which is audited (electricity with GOs) does not mix with the Product Electricity which is not audited (electricity without GOs). Electricity with GOs is traceable and a customer buying such a product receives that product, no other. Which anonymous agent (kWh) that physically delivers that specified Product Electricity is not important, just as it is not important which physical banknote you receive when you withdraw your money from your bank account. However, there must be a stable supply of power on the grid at all times and as more and more customers buy non-fossil power, less and less electricity is produced with fossil energy because less and less money is paid to producers of fossil power (Figure 5).

In a deregulated market it is the currents of money that rule and develop the power system, not the currents of electrons.
paradigm is embraced by the market, coal will not be replaced by natural gas. Coal however, will be replaced by specified renewable energy or nuclear energy. No power company will invest in production of fossil power as more and more consumers actively choose not to buy fossil power. Obviously, ‘Consumer Power’ on Nord Pool could have a big impact on which energy sources future investments are made in.

Discussion/Abstract reasoning

The proposed parallel between the Product Electricity, transferred on the electric grid, and Money, transferred on the "bank grid", can be evaluated by an upscaling in abstraction.

When travelling abroad you can withdraw your money from your account, and receive bills of a different currency. It is still your money being withdrawn e.g. in dollar bills from an ATM in Atlanta, Georgia or British pound sterling from a banking machine in London, England, even though the money deposited in your account was Swedish Crowns from your employer back home.

According to the proposed parallel between the Product Electricity and money, Eco labeled electricity from a Swedish windmill could be sold to a person living in Atlanta, Georgia. The audit would be conducted in the same manner: produced kWh in Sweden versus consumed kWh in Georgia and produced kWh in Georgia versus consumed kWh in Sweden. The first part signifying electricity sold from Sweden to Georgia and the second part signifying electricity sold from Georgia to Sweden. Both parties must participate, and the volumes of the specified Product Electricity bought and sold, must be equal.

However, this is only abstract reasoning to show that the proposed parallel is logically consistent. Electricity sales without the actual, physical transfer of kWh is highly unlikely to develop, though a common European electricity market is probable in the future. Then, on a common EU Power Exchange, Eco labeled electricity from a Swedish wave power station could be sold to a person living anywhere in Europe, e.g. London. This requires the same audit as the one being conducted today within the Nord Pool market: REDISS with Guarantees of Origins. Since electricity is balanced yearly, an annual audit would be sufficient.

What products are there to choose from?

On the Swedish electricity market there are a number of different products to choose from. The fact that there is no fossil power (with GO:s) offered as a product on the market, mirrors the popular unwillingness to buy electricity produced from fossil sources of energy. The same unwillingness to pay for fossil power, “mirrored” in the parameter “Willingness To Pay” (WTP), i.e. to pay extra for “Green Power”, was found in many of the articles reviewed [5,6,7,8].

There are 120 companies selling electricity in Sweden alone. The following 10 specified products are offered to the Swedish electricity consumers by the 20 largest sellers on the market, having a market share of over 85 % (Table 2):

<table>
<thead>
<tr>
<th>Power company</th>
<th>Market share</th>
<th>Good Environmental Choice (GO)</th>
<th>Renewable (GO)</th>
<th>Hydro (GO)</th>
<th>Wind (GO)</th>
<th>Locally produced Renewable (GO)</th>
<th>Off shore Wind (GO)</th>
<th>Nuclear (GO)</th>
<th>48 % Renewable</th>
<th>52 % Nuclear</th>
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<tbody>
<tr>
<td>Vattenfall</td>
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<td>☒</td>
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<td>X</td>
</tr>
<tr>
<td>E.ON</td>
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<td>☒</td>
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<tr>
<td>Fortum</td>
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<tr>
<td>DimEl</td>
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<tr>
<td>Bixia</td>
<td>5,6%</td>
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<tr>
<td>Jänkraft</td>
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</tr>
<tr>
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<tr>
<td>Telge Energi</td>
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<tr>
<td>Mälarenenergi</td>
<td>3,0%</td>
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<tr>
<td>Kraftringen</td>
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<td>☒</td>
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<tr>
<td>Öresundskraft</td>
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<tr>
<td>Skellefteå Energi</td>
<td>2,3%</td>
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<tr>
<td>Mölnadal Energi</td>
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<tr>
<td>GodEl</td>
<td>1,8%</td>
<td>☒</td>
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<tr>
<td>Billing Energi</td>
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<td>☒</td>
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<td>X</td>
</tr>
<tr>
<td>Nordic Green Energy</td>
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<td>☒</td>
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<td>☒</td>
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<td>X</td>
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<tr>
<td>Umeå Energi</td>
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<tr>
<td>Energi Forsälj Sverige</td>
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<td>☒</td>
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<tr>
<td>Jonköping Energi</td>
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<tr>
<td>Karlstad Energi</td>
<td>0,8%</td>
<td>No license</td>
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<tr>
<td>Share of Power market</td>
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</tr>
<tr>
<td>Others</td>
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<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 2: Swedish electricity consumers by the 20 largest sellers on the market.
1. 100 % Good Environmental Choice Electricity (Bra Miljöval El)
2. 100 % Renewable electricity (every company selling electricity could sell this electricity, with GO:s)
3. 100 % Hydropower
4. 100 % Wind power
5. 100 % Renewable electricity produced locally (without any def. of what is “locally produced”)
6. 100 % Wind power from off-shore wind farms
7. 100 % Nuclear power
8. Vattenfall own production mix16 (52 % nuclear, 46 % hydro, 2 % wind and solar)
9. 100 % Solar power
10. 100 % Swedish Solar power, only from Telge Energi

In addition to these 10 products there are a number of wind power cooperatives offering 100 % cooperative wind power, some are Eco labeled with Good Environmental Choice, some are without the Eco label.

Norway, Denmark and Finland

According to the REDISS summary of 2014 and 2016 there are large differences between the Nordic countries in the amount of Untracked Consumption. In the Nordic countries people are equally aware of the dangers of climate change. However, the new paradigm where electricity is a diversified product with different fossil content has not yet been largely accepted by the Norwegians, the Danes and the Finns. There has even been a ruling by the Norwegian Consumer Authority in 2010 that ruled marketing of “Green Power” illegal. Clearly, this was a misguided ruling because it was a decision done using the traditional perspective.

Final Residual Mixes, Untracked Consumption (Electricity sold without GO:s) was in:

1. Denmark 2014: 93,94 % Denmark 2016: 92,62 %
2. Norway 2014: 83,72 % Norway 2016: 84,20 %
3. Finland 2014: 74,80 % Finland 2016: 73,58 %

Conclusions and Recommendations

On a free market the price is determined as the equilibrium of supply (S) and demand (D) curves (Figure 6).

As demand for fossil power decreases (quantity Q decreases), so does the price (P). Power plants running on fossil energy will get less and less revenue as demand for fossil power diminishes. If (when) the price for a kWh of fossil power reaches a level lower than the production cost the production will halt.

Vice versa; as demand for fossil-free power increases so does the price. Power production from renewable energy sources (or nuclear) will get higher revenue as demand for fossil-free power increases. When the price for fossil-free power increases so will investments in fossil-free power production. The supply will then increase, and thus the price of fossil-free power will decrease. A free market produces whatever the consumers are willing to pay for. The power market is no exception to this rule. The power market could supply 100 % fossil-free power, if that is what the customers choose to buy. A very large majority of customers in Sweden do not want to buy fossil power, nor do the majority of consumers in other countries trading their power on Nord Pool. Coal is a ‘four-letter-word’ in many countries. Possible political decisions could include such laws that require state-owned companies, national agencies, municipalities and the whole public sector to buy 100 % fossil-free power.

Nord Pool could be the first Power Exchange trading 100 % renewable energy. The first step in this transition could be to differentiate the exchange into two product categories; Eco labeled electricity and Nord Pool Residual Mix. This study concludes that ‘Consumer Power’ in deregulated electricity markets could affect major investment decisions in power companies.

Recommendation to the EU

In REDISS it is allowed to sell the GO:s without selling the electricity that the GO was “tagged” to. This has increased the popular misconception and greatly reduced the transparency and credibility of the REDISS-system. E.g. Vattenfall can sell “Solar Power” in Sweden by buying GO:s from PV production in Italy without actually buying that solar PV produced power. That makes the whole idea of the new paradigm suspicious. It loses credibility. My recommendation after working over 20 years with Eco labeled power, is to “glue” the GO to the Product Electricity so that no one can buy the GO without, at the same time, buy that electricity. To understand this, one has to understand the new paradigm. My hope is that this article has explained in detail how the new paradigm works and that not all power mixes on the electric grid. Only power without GO:s mixes. Power with GO:s does not mix. Only the kilowatt-hours mix. That is the new paradigm.

Recommendation to the Swedish Energy Markets Inspectorate

Since 2013 all Baltic states trade all their power on Nord Pool. Consequently all power from Estonia, Latvia and Lithuania should be treated as if it was from Nord Pool.

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1https://www.vattenfall.se/elavtal/energikallor/elens-ursprung/
4http://www.fobbrukenborud.no/asst/3759/1/3759_1.pdf
5https://www.nordpoolgroup.com/About-us/History/
be included and the “new” NRM (Nord Pool Residual Mix) calculated from all the 7 states trading at the Nord Pool power exchange: DK, NO, FI, SE, EE, LV, LT.

Competing Interests

The author declares no competing interests. The author declares that vested interests in the Fossil and Nuclear Energy industry has been actively opposing this Paradigm shift.

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Historic Perspective on the analogy between the Electric Grid and our Banking System.
Explaining the New Paradigm on Electric Power.

Per Ribbing and Mats Leijon

Abstract

Albert Einstein once said, “Any intelligent fool can make things bigger and more complex... it takes a touch of genius – and a lot of courage to move in the opposite direction.” We have dared to challenge what is commonly known as a “truth” about electric power and by doing so unveiled the possibility of using the strongest form of ‘Consumer Power’; consumer boycott – to help transition the electric energy system away from fossil energy. In this Perspective we offer a totally new understanding of what electric power is, in its economic/market sense. We believe that we have found a simple and most efficient way of transforming our deregulated electric energy systems, from fossil to sustainable. We appreciate that this is not a humble statement. Yet, we humbly ask you to consider embracing what we call the New Paradigm on Electric Power.

History of Swedish power system development

Sweden started its electrification quite early. In the late 19th century our first hydro power stations were built. In Västerås "the Turbine house" (Turbinhuset) started generating power onto the grid already in 1891. The three Kaplan turbines, each rated 90 horse-power together generated 270 hp, equal to 199 kW electric power.

In these early days of electrification the anonymous agent (the kWh) of the product being sold and the product itself: the Product Electricity [bought according to a power contract, delivered by an anonymous agent: a kWh] was identical, and the exact same. The kWh was the Product Electricity, and the Product Electricity was the kWh. The very same. All electric power consumed in Västerås came from that one hydro power plant. In today’s terms; in 1891 every power consumer in Västerås had ‘Green Power’ in their outlets (without making an active choice).

Swedish Nobel prize laureate Svante Arrhenius played an important role in developing hydro power instead of coal power in Sweden.\[1\] Swedish hydro power continued to grow and became the backbone of Sweden’s industrialisation. From a climate perspective, this was a very important and positive choice. \[2,3\]

In 1963 a coal fired power plant was built in Västerås and was connected to the electric grid. A transformer station and a distribution system operator was in charge of distributing the produced kWh:s. From the same second the transformer station was connected there was no way of knowing where the kWh:s from the coal fired power plant were consumed and where the kWh:s from

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Turbinhuset hydro power station were consumed. The kWh:s were (and are) anonymous and interchangeable. The electromagnetic field with power $P$ [W] available on the electric grid was (and is) a mixture of the different electromagnetic waves that were (and are) superposed on the electric grid. In today’s terms; since 1963 the power consumers in Västerås has had ‘Mixed Power’ in their outlets. Actually, they already had ‘Mixed Power’ in their outlets since Sweden has had a national interconnected electric grid since the early 20th century with many different forms of electricity (also fossil) all mixed on the grid. It was only ‘Mixed Power’ that was being sold, and bought, because there was no audit of produced kWh:s versus sold kWh:s made at that time. And so it was, up until 1996, when the Swedish Power Market was deregulated and Ecolabeled Power became an option for all consumers. The consumers could now choose to have either ‘Mixed Power’ or ‘Green Power’ e.g. Ecolabeled Power (Bra Miljöval El), in their sockets. Still, there was no way of knowing which kWh:s they were physically consuming but the audit made of produced kWh:s versus consumed kWh:s guaranteed that they only received Ecolabeled Electricity – had they made that choice. That crucial audit is now part of the EU-system REDISS (Reliable Disclosure of Electricity Production) where Guarantees of Origin (GO) are saved (stored) and then cancelled (nullified) only after the consumers physically have consumed the anonymous agent (the kWh). What power (what electromagnetic wave with power $P$ [W]) they physically have consumed is as impossible to know as it was before the audit was made, but with the audit made – and the cancellation of one (1) GO per consumed kWh – now has defined that power to be no other power than exactly that power the consumers have signed a contract to buy; the Product Electricity. That product has different environmental loads depending on what power has been signed a contract to buy.\[4\]This is the new paradigm on Electric Power.

![Bank Grid vs Power Grid](image)

**Fig. 1. The de-facto choice**

However, "no way of knowing" did (and does) not mean: no way of knowing what electricity to pay for, and to what power company to pay the bill. The Product Electricity that you receive, and
consume, you pay for according to your signed contract with the power company of your choice, and with the environmental load of your choice.

Electric power is, as we all know, consumed in the same instant as it is produced. This fundamental physical fact has unfortunately clouded the judgment of many engineers and mistakenly been used, and is still used, as an argument against 'Consumer Power' on the Power Markets. One must then think a little bit further and understand that the Power Market, as all markets, is ruled by the law of Supply & Demand. The Power market is not ruled by the laws of Ohm and Kirchhoff. Those laws rule the power grid. [5] Electric power cannot be stored, but Guarantees of Origin (GO) can be (and are) stored. When ‘Green Power’ is consumed the GOs are nullified and an audit is made controlling produced versus consumed kWh:s with GOs.

The intersection between the two lines Supply & Demand is the so called "Price point" (P) or Equilibrium Point. [6]

![Fig. 2. The Equilibrium Point (P)](image)

This is common knowledge in all markets. The Power Market is no exception. All, every single one, of the articles on ‘Green Power’ and ‘Consumer Power’ that we have studied has been written in the old, physical, perspective, e.g. [7,8,9,10,11,12,13,14,15,16,17,18]. Especially clear in its misunderstanding is the article “Green Power Marketing Claims: A Free Ride on Conventional Power” published in The Electricity Journal [19]. From that flawed perspective follows these misunderstandings that:

i) Only after everyone has decided to choose to buy ‘Green Power’ – only then will you have ‘Green Power’ in your outlets (sockets).

ii) Since electricity is mixed on the grid you don’t get what you buy. Hence, marketing and sales of ‘Green Power’ is a hoax. [iii]

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[10] Claes Göran Kjellander, Dagens Nyheter 1996-01-17 "Konsten att tjäna gröna kronor" (Green Power is a hoax)
When, in reality, you can choose to **not** have coal power in your outlets (sockets), already today.

Any deregulated market will supply all customers with the product they demand (= are willing to pay for). N.B: we focus here on what consumers **don’t** want. A consumer boycott of coal power would be a great push for the necessary transition away from fossil energy.

Hypothetically, quite hypothetically, if 100 % of the power consumers in Sweden did choose 100 % solar power the market would supply exactly that. However, it would be at an extremely high price per kWh since enormous amounts of batteries, e.g. hydrogen, molten salt, pumped hydro, or any other form of energy storage for solar electricity, would have to be built and paid for. The 100 % solar power scenario would simply not happen. It would be far too costly. A scenario with 100 % renewable power, however, is both feasible and quite probable. This development is logical and price driven since the prices of new solar PV, new land based wind power and new offshore wind power has decreased substantially while the price for new nuclear power has increased. Today you get roughly twice the amount of kWh per year if you invest in wind compared with nuclear. See e.g. Lazard LCOE 2017.\(^{[20]}\)

![Renewable Energy—Historical Cost Declined\(^{[20]}\)](chart)

**Fig. 3. New Renewable Power is now cheaper than fossil and nuclear**

We also see new renewable power technologies emerging \(^{[21]}\). Pilots of wave power and current power (both marine and in rivers) are being built. The success or failure of these new technologies is heavily depending on the (falling) prices of offshore wind power and solar PV power.
In Nature Energy, November 2016 issue, an article was published that strengthened the view that a 100 % renewable power system in the Nordic countries could be feasible. From that article we learn that a fully renewable system is feasible, “if properly balanced by hydropower”. [22]

We argue that there are plenty of fossil-free solutions to both engineering challenges (power regulation + energy storage) other than the existing hydropower which has a flexibility and regulation capability of handling at least 11 GW installed wind power [23] compared to the current 7.6 GW(iv).

If an increased need for energy storage and power regulation arises, there are a number of solutions. Described in terms of the analogy with the Banking System; the responsibility of keeping the grid stable at 50 Hz is parallel to the responsibility of keeping all banks and ATMs stacked with enough banknotes for allowing variable withdrawals, large and small, at any and all times, every day.

Fig. 4. The analogy: Bank Grid parallel with Power Grid

iv According to Swedish Wind Energy: https://swedishwindenergy.com/
N.B: The banknotes are anonymous and interchangeable. There is no way of knowing if they did come from a drug sale or any other criminal business. But you know, for sure, that you can only withdraw your own money from the bank or ATM. You can never withdraw anyone else’s money.

Solutions for keeping the electric grid “stacked with kWh:s” (using the analogy with banknotes) at all times include e.g. Pumped Hydro installations, Batteries, Flywheels, Biogas GCC or even H₂ storage coupled with a Fuel Cell to produce power when needed. The market will choose the most efficient solutions that solve the task at hand; energy storage and power regulation.

A new paradigm on power

The new paradigm is explained in the pedagogical four-square (Fig. 1). It really is that simple! Banknotes are anonymous. They mix. No moral choice comes into play. You receive banknotes at the ATM or at the cashier's counter at the bank. You never know where those specific banknotes came from, and even if you did, it wouldn't matter. It's your money. No one else's.

Money, on the other hand, is not mixed and here there is moral at play. You can choose to have only clean, legitimate, money on your account - or - you can sell drugs and deposit drug-money into your account. Then, when you make a withdrawal, you withdraw drug-money. That is a moral choice of what kind of money you withdraw.

The parallel is exact; you cannot know from what generator your anonymous kWh comes from – but you can choose what power it is. That is a moral choice. This separation of different kinds of the Product Electricity is only possible if there is an audit made. And it is. REDISS is the EU-system that guarantee that you receive exactly the power you buy.

The first peer-reviewed scientific article to explain the new paradigm on power on deregulated power markets is #154 in the International Journal of Earth and Environmental Sciences [24]. The article explains how ‘Consumer Power’ can, and probably will, (if accepted) play a part in the development of the future energy systems. This is the second paper explaining the New Paradigm on Electric Power.

Conclusion

We conclude this short Perspective by inviting you; “Welcome. Please enter into the new paradigm.” It is just an old misunderstanding that all power mixes on the grid. It does not. Power is a product; the Product Electricity. We sign contracts to buy power; power contracts. Different kinds of power has different environmental loads. Anyone who likes nuclear power can buy nuclear power. Anyone who likes renewable power can buy ‘Green Power’.

The different products are delivered to the consumers by anonymous agents: kWh. They mix. The Product Electricity does not. The REDISS-system guarantees that you receive exactly that power that you have signed up to buy. Understanding this, is understanding the new paradigm. Any consumer in the Nordpool market who does not buy Ecolabeled power – or any other power with GO – buys the dirty, fossil mix commonly known as ‘Ugly Power’. The Nordic Residual Mix has over 40 % fossil energy.
Let us end by high-lighting the possibility that the New Paradigm on Electric Power could assist our society in increasing the speed of our necessary transition away from fossil energy by exemplifying with another Nature Energy Perspective [25]. In that article it is described as something positive that a transition from one fossil fuel (coal) to another (natural gas) has been made rather swiftly, because of primarily economic reasons. But if we listen to the latest report by IPCC we have no more time for making new investments in fossil energy, even if it has lower emission and is, with an obvious anomaly, called “clean electricity”. We must stop using fossil energy altogether. We should, instead, try and steer investments in the direction of fossil-free energy.

Here is the great benefit, the ‘clou’ of the new paradigm: Consumers can choose not to buy fossil power. The fact that this is a de facto choice, a strong ‘Consumer Power’ movement against fossil power is a real possibility. Imagine the possibility of a consumer boycott of fossil power. No power company will risk their money in a high risk venture of investing money in a power production facility that produces a Product Electricity where there is an obvious risk that sooner or later no one will buy that Product Electricity, no one will pay for the power produced there. The enormous power of ‘Consumer Power’ when choosing not to buy fossil power (if a large enough part of the market is doing it) no lobby organisation can subdue. Consumer boycotts can be lethal, history has shown. Political decisions, however, can be and are, lobbied against all the time. But you cannot lobby against a popular movement. That is a fact and the new paradigm on electric power could become a great help for this popular movement. Let’s help make it become real. As soon as possible.
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