Climate Change Leadership – the case for Electrification

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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.” Submitted to Energy, The International Journal, April 10, 2019
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Paper I
Paper II
Abbreviations:

k  kilo \( (10^3) \)
M  Mega \( (10^6) \)
G  Giga \( (10^9) \)
T  Tera \( (10^{12}) \)
P  Peta \( (10^{15}) \)
E  Exa \( (10^{18}) \)
Z  Zetta \( (10^{21}) \)
Y  Yotta \( (10^{24}) \)

Watt  W
kiloWatthour  kWh
Joule  J
second  s
Ws  Wattsecond
1 Ws  =  1 J
1 kWh  =  3,6 MJ

C_f  Capacity factor

EV  Electric Vehicle

GO  Guarantee of Origin
REDISS  Reliable Disclosure of Electricity Production (EU)
AIB  Association of Issuing Bodies (EU)
EU  European Union
FSSD  Framework for Strategic Sustainable Development
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 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 electric outlets (sockets).

ii) Arguments against Green Power has been along the line: Since all 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).

However, since August 13th 2018 when the article:

1 Claes Göran Kjellander, Dagens Nyheter 1996-01-17 “Konsten att tjäna gröna kronor”
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](image1.png)

Fig. 1 Four-square over the parallelism between bank system and power system

2.2 The power stability parallel

![The power stability parallel](image2.png)

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\(^2\) 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 costumer 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\(^6\).

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.

![Image](https://www.aib-net.org/facts/national-datasheets-gos-and-disclosure)

- Money is stored in a bank account
- GOs are stored in an audited account
- Electric Power cannot be stored - but:
- Energy to produce power can be stored in many different ways, e.g. (HBF)\(^2\)

Fig. 3 The energy storage parallel

2.4 Examples of energy storage and power regulation solutions

Storing energy can be done in many ways, see A to Ω in chapter 6: “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. CH\(_4\), C\(_2\)H\(_6\), CH\(_3\)OH, C\(_2\)H\(_5\)OH)
- Fuel cells (for power production)

\(^2\) https://www.aib-net.org/facts/national-datasheets-gos-and-disclosure
2.5 The accepted abstraction – and the new abstraction for Electric Power

The abstraction that we since ages take for granted when it comes to banknotes and money is that:

There exists no physical connection between the banknote and your money. Whatever banknote you withdraw from your account – is your money. No one else’s. The banknote is anonymous and interchangeable. The money you have in your bank account is the money you have deposited there. That money is the only money you can withdraw. No one else’s.

The new abstraction that we need to understand is the parallel between the anonymous kWh and the anonymous banknotes: (GO = Guarantee of Origin)

There exists no physical connection between the kWh you consume and the Product Electricity you have signed a contract to buy. No physical connection – but an audit of produced versus sold amounts of electricity. Whatever kWh you consume, one GO is cancelled from your GO-account. You consume your own power. No one else’s. The kWh is an anonymous and interchangeable agent of what Product Electricity you buy. The GOs you have in your GO-account is the GOs you have chosen to deposit there, e.g. GOs from wind power, solar power, hydro power or other Green Power. The power you have in your electric outlets (sockets) is the power you have chosen to have there. That power is the only power you can consume. No one else’s.

2.6 The De Facto choice

This new understanding of electric power challenges the old understanding quite dramatically. This means that we, as consumers, can choose to not have coal power in our electric outlets, just as we can choose not to have any drug money in our bank accounts. That is one way of expressing the parallelism.

This possibility of a fossil free choice of power opens up for a fossil free electrification of our society. Since it is now clear that we do have a de facto possibility of choosing what electricity we consume we have the possibility of choosing to consume only fossil free power.

Given that fact I will investigate if an electrification of our society, an electrification with only fossil free power, could be a possible solution to our climate crisis.
3. Alternatives to fossil power

This thesis will briefly describe 7 possible alternative solutions to fossil energy: one non-renewable, and 5 + 1 renewable. The 6 renewable solutions are:

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

3.1 Nuclear power

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 new solar PV power. See e.g. Lazard LCOE 2017[7].

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

The reactors at Hinkley Point, 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. New solar PV power and offshore wind power is now being commissioned at roughly half that price and land based wind power at around 4 Eurocents per kWh.
Still today we 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.\textsuperscript{[8]} 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.\textsuperscript{[9]}

The 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.\textsuperscript{[10]}

Hinkley Point is scheduled to go online 2025, 12 years after it was commissioned. 12 years to get another 2 600 MW nuclear generation capacity. During the last 12 years installed wind power has increased by 465 166 MW\textsuperscript{[3]}. Only in the year 2017 there was 52 552 MW new wind power capacity installed.\textsuperscript{[4]}

During that same time (2006-2017) there has been a decrease in global nuclear power production. See figure 5.

The target agreed upon in the Paris agreement\textsuperscript{[11]} is to keep global warming to a maximum of 2 degrees C, and pursue policies to try and keep it as close as possible to no more than 1,5 degrees C. Nuclear power could be a fossil free alternative source of power and the choice to consume only nuclear power is since many years offered on the market. Vattenfall, among others, offer a Product Electricity with 100 % EPD Nuclear Power. (EPD = Environmental Product Declaration).

\textsuperscript{3} http://gwec.net/global-figures/wind-in-numbers/
\textsuperscript{4} https://wwindea.org/blog/2018/02/12/2017-statistics/
3.2 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 electric power.

\[
\text{Carnot Efficiency } \equiv 1 - \frac{T_c}{T_h} \quad (T = \text{temperature, } c = \text{cold, } h = \text{hot})
\]

At room temperature (\(T_h = 20^\circ C\)) and with an outdoor temperature of 0°C (\(T_c\))\(^5\), this equals: \(1 - \frac{273,15/293,15}{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:

“\text{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. \(\text{COP} = \text{Coefficient Of Performance}\)^6.

\(^5\) 0°C ≈ 273,15 Kelvin
3.3 Solar Power; utility scale and small scale

Today large (utility scale) solar PV power projects are booming\(^7\).

1. Noor Complex Solar Power Plant, Morocco\(^8\) 580 MW  Completed: Late 2018
3. Longyangxia Dam Solar Park, China\(^10\) 850 MW  Completed: Mid 2015
5. Datong Solar Power Top Runner Base\(^12\) 1000 MW  Completed: June 2016
6. Bhadla Solar Park\(^13\) 1365 MW  Completed: Dec 2018
8. Shakti Sthala, Pavagada, Karnataka, India\(^15\) 2000 MW  Completed: End of 2018

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 kW\(_p\) solar PV with an estimated annual production of 91 000 kWh.

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\(^7\) https://en.wikipedia.org/wiki/List_of_photovoltaic_power_stations
\(^8\) https://en.wikipedia.org/wiki/Ouarzazate_Solar_Power_Station
\(^10\) https://en.wikipedia.org/wiki/Longyangxia_Dam
\(^12\) http://www.sunpowereddreams.com/the-largest-solar-power-plant/
\(^13\) https://en.wikipedia.org/wiki/Bhadla_Solar_Park
\(^14\) https://en.wikipedia.org/wiki/Tengger_Desert_Solar_Park
\(^15\) https://en.wikipedia.org/wiki/Pavagada_Solar_Park
3.4 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.
3.5 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.

Fig. 9 a, b, c, d, e – Wind powered pumped hydro in Gaildorf, Germany
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.\(^\text{16}\)

**GLOBAL CUMULATIVE INSTALLED WIND CAPACITY 2001-2017**

![Graph showing global cumulative installed wind power capacity 2001-2017](image)

Source: GWEC

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 \((C_F)\) of 63 % will be built during 2019 in the harbour of Rotterdam\(^\text{17}\). 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 Investment). Modern WTGs have EROI-values around 50.\(^\text{12}\) The EROI-value is sometimes referred to as EROEI (Energy Return On Energy Invested) or ERoEI.

### 3.6 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 \(^\text{18}\). The challenge now is not only the forces of Mother Nature but the drop in price of electricity from new offshore wind farms.

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\(^{17}\) https://www.genewsroom.com/press-releases/ges-haliade-x-12-mw-prototype-be-installed-rotterdam-284662

3.7 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 short exposé on new renewable 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 in itself 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)
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.\(^{(19)}\) Fourier based his idea on the so called “hot box” earlier constructed by Horace Bénédict de Saussure from Switzerland.\(^{(20)}\) 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\(^{(21)}\) 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\(^{(22)}\):

“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 this 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
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 CO$_2$ 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\.[14]

![Global average surface temperature change](image)

Fig. 6 Summary for Policymakers IPCC-AR5, 2013 (Fig 7 a)

![Global Land and Ocean Temperature Anomalies, January-December](image)

Fig. 7 Global temperature Anomaly relative 1901-2002, until 2018 NOAA, 2019
5. 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.

5.1 A to Ω

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  already used by www.svk.se
Ε – Ethanol and other Solar Fuels
Ζ – Zink Oxide Batteries
Η – H2 Energy Storage  www.vatgas.se
Θ – Thermal Energy Storage
Ι – Invest in Solar:  www.jointrine.com
Κ – Curtailment of Solar power(23)  “Inverters act as the brain of the PV system”
Λ – Li-ion batteries  www.northvolt.com
Ν – Na-ion batteries(15)
Ξ – Xenofobia - is not a solution. We are all one. Earth is our only home. See Ψ. Closely linked.
Ο – O2 Energy Storage(16)
Π – Pumped Hydro Energy Storage  e.g. Pumped Hydro by Wind (chapter 5.2)
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
Φ – Flywheel Energy Storage(17)  www.beaconpower.com
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.

5.2 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 6: Discussion.
6. Discussion

6.1 Potential of renewable electric energy

The annual influx of solar energy possible to use for energy conversion is:\[18\]

- $89 \text{ PW} \times 8766 \text{ h} \times 3600 \text{ s} = 2,809 \times 10^{24} \text{ Ws} = 2,8 \text{ YJ}$ (see Fig. 16)

The annual use of energy (all energy: electricity, heat, fuels) was according to IEA, International Energy Agency, 13759 825 ktoe which equals 576 EJ (or 0,000576 YJ) in the year 2016.\[19\]

Since the relation $2,8 \text{ YJ} / 0,000576 \text{ YJ} = 4861$ 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. In 2 hours, Earth has received: $89 \text{ PW} \times 2 \text{ h} \times 3600 \text{ s} = 640 800 \text{ PWs} = 640 800 \text{ PJ} = 641 \text{ EJ}$. Since $641 > 576$ we conclude that 2 hours is more than sufficient - 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, by all people, in 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), and only Green power to power our industry and other economic sectors leads me to my conclusion, and my most sincere recommendation: to electrify our society with 100% renewable free-flowing energy.

6.2 Electricity for our society

Solutions for the power sector, as described above, are abundant\[20\]. 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 CO$_2$, globally. Emissions are ~40 Gton/year, including AFOLU the emissions are ~50 Gton/year\[21\].

AFOLU = Agriculture, Forestry and Other Land Use.

Fossil fuels are also used in the transportation sector, industry, buildings and other energy sectors.
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[22]. 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. 19 The 8 Sustainability Principles in FSSD. First order principles for a sustainable society.
6.3 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 is 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.

![MUT η map](image)

**Fig. 20 Energy efficiency of an Electric Motor. MUT = Motor Under Test**

Energy efficiency is the percentage of energy output as a result from an energy input. The quota $P_{in}/P_{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: “Historic Perspective on the analogy between the Electric Grid and our Banking System.”

6.4 Electrification of the industrial sector

Already today (2019) large EV producers have addressed the problem of CO2-emissions from their production of EVs and are now 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.\cite{25}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig_21_VW_EV_ID-series.png}
\caption{The VW EV ID-series}
\end{figure}

\cite{25} Video in Swedish: https://www.youtube.com/watch?v=w40dnd69waY&feature=youtu.be
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, trikes, buses, scooters, lorries.

6.5 Electrification of other economic sectors

In other sectors of society where fossil energy is used the same basic truth holds true; the amount of clean, free-of-charge, solar energy that is given to us all the time is > 4000-fold what we use today, totally, globally. To change from fossil fuels or fossil power over to renewable electricity is a possibility that lies in line with the Paris Agreement.

Only, of course, if the choice of fossil free power is made. That is the ‘clou’ of this new understanding of Electric Power – the possibility of not consuming any fossil power.

6.6 Summary of Discussion

In this thesis I have shown that:

I. We can choose what power we consume; e.g. 100 % free-flowing renewable. (ch. 2)
II. New renewable power is cheaper than new non-renewable power. (chapter 3)
III. The potential of renewable energy is 4000-fold what we use today. (chapter 6.1)
IV. The electric motor is fossil free when powered by clean power. (chapter 6.3)
V. Industry and other sectors can be fossil free when powered by clean power. (ch. 6.4)
VI. The production of Green power and the regulation and storage needed for intermittent energy sources has many solutions that can be installed already today.
   The solutions exist. The market will choose the most efficient ones. (chapter 5)

In conclusion; if we start to electrify our society with the active choice of only using fossil free power, we will take a big step towards solving our climate crisis.

The 6 facts above, in my view, results in that this is a logically consistent, scientifically sound 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 PV power is Solar Energy  
7. Solar Thermal power is Solar Energy  
8. Solar Thermal heat is Solar 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 - Framework for Strategic Sustainable Development[23].

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.
7. Conclusion

Sweden and the Nordic countries can contribute to the solution of the climate crisis by electrifying its societies with renewable power from free-flowing solar energy sources such as wind, wave, current, hydro and solar PV.

I recommend:

- 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.

The possibility of a swift energy transition from fossil fuels to renewable electricity is made possible 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. This is new knowledge.
8. Personal endnote

In 1995 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
9. 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 12\textsuperscript{th} 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.

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. Submitted to Energy, April 10, 2019.
10. 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.


BANKNÄT  ELNÄT

<table>
<thead>
<tr>
<th>sedlar (blandas)</th>
<th>kWh (blandas)</th>
</tr>
</thead>
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Både sedlar och kWh är anonyma och utbytebara. Inget moraliskt val finns att göra.

När det kommer till pengar och ursprungsmärkt el utförs en revision = Ett moraliskt val finns att göra.


  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

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.
11. 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.

Big 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.

Mats – we have spent lots of time on developing the science of Electricity. It has been really exciting! Extra thanks for all personal support.

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 Silinš 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 strategically into sustainability. Thank you also for all personal help.

A warm note of appreciation to my dear friend professor Magnus Odén who has helped me greatly with ‘drying up’ my thesis.

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. 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.

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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 H₂ tank. It could also be converted into hydrogen gas and stored in a gas tank. But electricity, in itself, cannot be stored. That's fundamental physics, not a matter of economics or physics.

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

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

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

\[ W_0 = W_1 \quad \text{Energy is always preserved} \]  
\[ (2) \]

\[ \Sigma I = 0 \quad \text{The sum of currents flowing into and out of a node always equal zero} \]  
\[ (3) \]

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.

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

\[ W_o = P \cdot t \quad \text{Electric Energy (W_o) equals the product of Power (P) and time (t)} \]  
\[ (5) \]

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).

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: \( P_{\text{produced}} \cdot P_{\text{consumed}} = 0 \) (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 have 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). NRM is unspecified electricity, so ceasing to buy unspecified 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 unspecified upstream. The other alternatives are not, because they are all audited and sold with their Guarantees of Origin.
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].

And that I say after over 20 professional years in the energy and power sector. I conclude that a majority of customers would stop buying fossil power if they knew they had that choice. Additionally, a reduced demand for fossil power also implies increased investments in energy efficiency and more investments in renewable power production.

My studies, conducted over a more than 20 year long period (since 1997), show that the possibility to single out, and stop buying, power produced 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].

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</table>

Table 1: Fossil fuels consumed in Swedish power production.
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 (α 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 Blyth in the United Kingdom. The NSN Link (North Sea Network) will be a part of the North Sea 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 Ohm8 and Gustav Kirchhoff9 - 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.3 With the new perspective it is evident that at 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 Norway9. 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 power9. This Residual Mix is calculated by the Swedish Energy Markets Inspectorate (www. ei.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.

3Suggestion: 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.
6http://www.ei.se/sv/for-energiforetag/el/utropsmarknadsav-EL/
"It's just a scam"
different ways mocked and scorned the idea of Eco labeled electricity.
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a misconception.
green customers will translate into a change in the electricity mix. 
properly - i.e. double-selling is avoided - the purchasing decisions of 
a green power customer does not get a physically different product, 
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 different ways mocked and scorned the idea of Eco labeled electricity. "It's just a scam" was their message, since all electricity was mixed11. That was the logical reasoning following the traditional perspective. Contrarily, with the new perspective, consumers have a real, de facto, choice of what power they buy and consume.

In the Physical Perspective, the electromagnetic fields on the grid are perceived as currents of water in a pipeline system. In this perspective all different kinds of electricity are mixed on the grid. A common picture describing this traditional perspective is a bathtub into which electricity from different power plants is “poured” hence the Physical Perspective is also referred to as “the Bathtub Model” (Figure 4) by most people in the trade.

11Claes Göran Kjellander, Dagens Nyheter 1996-01-17 "Konsten att tjäna gröna kronor"

Into the bathtub green, blue, grey or black electricity is supplied. Let green stand for new renewable electricity such as wind, wave, solar and marine current power. Let blue stand for existing hydropower, grey for nuclear power and black for electricity produced from fossil energy such as coal, oil and gas.

Apparent lack of logic of the physical perspective

Before 1996 the Swedish electricity market was essentially a monopoly. Customers had to buy their electricity from the utility running the electric grid in their area. Looking at the Product Electricity with the Physical Perspective the customer had the same mixed electricity then as after the deregulation. If, as the Physical Perspective states, electricity is to be considered parallel to water flowing (and mixing) on the grid there was no way of knowing what electricity a specific consumer got. Nevertheless, people paid their power bills to their utility not posing any arguments as to what electricity (from whose production) they were actually receiving. Questions of whose electricity a specified customer received became common only after the deregulation of the electricity market. This is inconsistent since the grid was not altered, in any way, by the deregulation of the market.

Furthermore, what kWh is physically consumed is non-significant from a market point of view. Contrary to common perception it is of no significance what actual product the consumer physically consumes after executing his/her 'Consumer Power'. E.g., a man buying organic bananas in the store is executing his 'Consumer Power'. If he later on trades the organic bananas with his neighbor's conventionally produced bananas and consumes those bananas instead, he still has had an impact on the market of bananas. 'Consumer Power' is executed in the purchasing moment, not in the consuming moment. Indeed, a parallel with the product discussed here: the Product Electricity.

The new perspective: the Bank Parallel

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.

Notae 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.

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."

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11Claes Göran Kjellander, Dagens Nyheter 1996-01-17 "Konsten att tjäna gröna kronor"
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 ATMs 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

\[
\text{Physical property of grid stability:} \quad \text{if } P_{\text{production}} < P_{\text{consumed}} \quad \text{then } f \text{ decreases until } P_{\text{production}} = P_{\text{consumed}}
\]

\[
\text{if } P_{\text{production}} > P_{\text{consumed}} \quad \text{then } f \text{ increases until } P_{\text{production}} = P_{\text{consumed}}
\]
Reliable Disclosure (REDISS) and its GO:s (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 Energii or “nuclear power”, sold by e.g. Vattenfall 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 GO:s 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 projects that reduce the use of (electric) energy.

Results

The proposed new perspective on electricity as a specified product on a non-monopoly market suggests that a person buying a specified kind of electricity which is audited by a third party, e.g. 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 projects that reduce the use of (electric) energy.

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. 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.

Figure 5: The pedagogical foursquare (2nd).

The necessary audit

In the new paradigm all electricity which is audited (electricity with GO:s) can be traced, hence it does not mix, whereas electricity which is not audited (electricity without GO:s) 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 GO:s 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 productions 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 audited electricity with GO:s, 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 Residual 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...
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 GOs) 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 (GO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vattenfall</td>
<td>18,0%</td>
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<td>X X</td>
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<td>E.ON</td>
<td>12,9%</td>
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<td>DinEl</td>
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<td>Bixa</td>
<td>5,6%</td>
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<td>Jamtakraft</td>
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<td>Hafslund (Norge)</td>
<td>4,0%</td>
<td>No license</td>
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<td>Telge Energi</td>
<td>3,2%</td>
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<td>Mälarenenergi</td>
<td>3,0%</td>
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<td>Kraftringen</td>
<td>2,8%</td>
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<td>Öresundskraft</td>
<td>2,3%</td>
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<tr>
<td>Skellefteå Kraft</td>
<td>2,3%</td>
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<td>Mölndal Energi</td>
<td>1,9%</td>
<td>X - X</td>
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<td>GodEl</td>
<td>1,8%</td>
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<td>Billing Energi</td>
<td>1,0%</td>
<td>No license</td>
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<tr>
<td>Nordic Green Energy</td>
<td>1,0%</td>
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<tr>
<td>Umeå Energi</td>
<td>1,0%</td>
<td>X - X</td>
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<tr>
<td>Energi Försälv Sverige</td>
<td>0,9%</td>
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<tr>
<td>Jönköping Energi</td>
<td>0,8%</td>
<td>No license</td>
<td>X</td>
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<tr>
<td>Karlstad Energi</td>
<td>0,8%</td>
<td>No license</td>
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<td>Share of Power market</td>
<td>85,3%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Others</td>
<td>14,7%</td>
<td></td>
<td></td>
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</table>

Table 2: Swedish electricity consumers by the 20 largest sellers on the market.
The price for 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 other countries trading their power on Nord Pool do not want to buy fossil power, nor do the majority of consumers in other countries trading their power on Nord Pool.

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:\n
1. Denmark 2014: 93.94 %
2. Norway 2014: 83.72 %
3. Finland 2014: 74.80 %
4. Sweden 2014: 27.45 %

The recommendation to the EU

In REDISS it is allowed to sell the GO:s without selling the GO:s mixes. 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.

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.

In REDISS it is allowed to sell the GO:s without selling the GO:s mixes. 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.

Conclusions and Recommendations

1. 100 % Good Environmental Choice Electricity (Bra Miljöval El)
2. 100 % Renewable electricity (every company selling electricity could sell this electricity, with GOs)
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 mix\(^2\) (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\(^3\). 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\(^4\). Clearly, this was a misguided ruling because it was a decision done using the traditional perspective.

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

1. Denmark 2014: 93.94 %
2. Norway 2014: 83.72 %
3. Finland 2014: 74.80 %
4. Sweden 2014: 27.45 %

Conclusions and Recommendations

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

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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\(^5\) 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 (https://www.ei.se/en/)

Since 2013 all Baltic states trade all their power on Nord Pool\(^6\). Consequently all power from Estonia, Latvia and Lithuania should

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\(^1\)https://www.vattenfall.se/elavtal/energikallor/elens-ursprung/
\(^4\)http://www.fofrbrukerombudet.no/asset/3759/1/3759_1.pdf
\(^5\)https://www.vattenfall.se/elavtal/energikallor/elens-ursprung/
\(^6\)https://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.

Per Ribbing¹ and Mats Leijon²

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 this new understanding of what Electric Power is.

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.²³

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 to the grid there was no way of knowing where the kWh:s from the coal fired power plant were consumed and where the kWh:s from Turbinhuset hydro power station were consumed. The kWh:s were (and are) anonymous and

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interchangeable. The electromagnetic field with power $P \text{ [W]}$ 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 electric outlets (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 $P \text{ [W]}$) 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. This is a new understanding of how exactly your electricity is brought home to you. Not anyone else’s electricity.

**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]

![Equilibrium Point Diagram](image)

**Fig. 2. The Equilibrium Point (P)**

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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[6] 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 electric 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.\[20\]

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”.\[21\]

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\[22\] compared to the current 7,6 GW\[iv\].

If (when) 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.

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* 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 understanding of electric 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 want to 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 GOs are properly audited.

When this new understanding of electric power has sunk in we see that:

- if you buy 100 % solar power with GOs you have solar power in your electric outlets even during the night.
- if you buy 100 % wind power with GOs you will consume only wind power even if there is no wind.

  Both these statements holds true in the new understanding of 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 Ecolabelled power – or any other power with GO – buys the dirty, fossil mix commonly known as ‘Ugly Power’. The Nordic Residual Mix holds over 40 % fossil energy.

Let us end by high-lighting the possibility that the new understanding of 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 [23]. 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.
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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