International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 1154

Global and local Challenges and needs for research in sustainable energy systems– Experiences from Sweden

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Abstract

Increasing global population and consumption are drivers for energy consumption. As the major part of primary energy sources are still fossil, the accumulated Green House Gases continues to raise in the atmosphere. Embedded in the strategies to achieve the UN 2030 Sustainable Development Goasl are high urbanisation rates and high annual economic growth (7 %) in emerging economies. It seems more and more obvious that the transition to more energy- and resource-efficient cities will be gradual and take longer time than expected. It is also clear that transitions have to be anchored in a local context at the urban level where all key actors take part in the planning process. Urban systems are examples of very complex systems and the study of complex systems is about understanding indirect, sometimes unwanted effects. Sweden has very ambitious goals to reduce GHG emissions. However, the path towards the goals seems very winding. In 2018 the emissions increased even when using a production-based calculation. There are still uncertainties of the main goal in Sweden since two concepts are used in the debate. One is fossil fuel free energy mix and the other renewable energy mix. Both have a focus on minimizing GHG emissions but the fossil fuel free energy mix accepts nuclear energy as a part of the mix. One of the most difficult targets is to reduce GHG emissions in the transport sector. Here we can find clear examples of conflicting goals and short- and long-term targets. Biofuels can reduce the GHG emissions but will have negative effects of biodiversity and food production. Attempts to ban diesel cars will reduce the potentials for using biofuels in the traffic sector. This paper will analyse the efforts in Sweden for developing a more sustainable energy system and draw conclusions of barriers and generalisation to other countries and also to draw conclusions around research issues needed to be explored..

Keywords
Fossil energy, Renewable energy, transition of energy system, Sweden's energy mix

1. Introduction

Energy is the fundamental resource for urban and social development including reduction of poverty in the world. Also, material transformation from virgin materials or through recycling in a circular economy is dependent on the availability of energy at a reasonable price. Today the main primary energy sources are fossil fuels (Figure 1). The reason for this is obviously that fossil fuels have a very high energy density (Chemical energy) and are still rather cheap and technically easy to convert to other forms of energy compared to other energy sources. To meet global challenges in the very long run there will have to be a transition to close to 100 percent non-fossil energy for two main reasons. The first is that depletion of fossil energy sources will increase the prices and secondly combustion of

fossil energy sources is connected to negative environmental impacts both on local and global level. However, it's becoming more and more clear that the transition will take longer time than might be anticipated today, and that we have to find solutions that not only solve global environmental impacts but also development of people's conditions on local level. It is essential that applied energy research is supporting this development in a fruitful way by system analysis in both local and global contexts. It will probably be so that the developing countries first will have a phase of using more fossil energy to support growth of welfare, before they can enter as state of decreasing use of energy. This is how the developed countries did historically. In the UN 2030 Sustainable Development Goals [1] there is a clear insight of the relation between energy consumption and Human Development Index (HDI). More energy is needed to reduce poverty in the world. The "hope" is that the transition to renewable and clean energy can go faster than might be realistic even with an annual economic growth of 7 %. If not, there is a risk for a backlash for the goals, which will be serious when realizing the failure with the earlier millennium goals. Population growth, economic growth, and increasing consumption are important drivers for higher energy consumption. According to a report world hunger is on the rise: the estimated number of undernourished people increased from 777 million in 2015 to 815 million in 2016 [2]. The report also noted that slowdown in global growth has had a negative impact on people's ability to get enough to eat. So, we are in a situation where we need GDP growth to decrease poverty, but there is a significant positive relationship between growth in energy use and growth in GDP for all countries taken together and for all subsets of countries, although not necessarily proportional. There is some indication that growth in energy use declines with GDP per capita, for any given growth in GDP. We can conclude that developing countries will need more energy to raise there HDI. Even if energy efficiency can be raised the rebound effects from higher consumption will counteract and energy consumption will continue to rise. The increasing demand of energy in developing countries are closely linked to urbanization. By 2020, the majority of people in developing countries will live in cities and, by 2050, the urbanization rate in developing countries will reach 63.4 percent, not far off the global average of 66.4 percent. UNDP Urban strategies. From an estimated 7.7 billion people worldwide in 2019, the medium-variant projection1 indicates that the global population could grow to around 8.5 billion in 2030, 9.7 billion in 2050, and 10.9 billion in 2100. With a projected addition of over one billion people, countries of sub-Saharan Africa could account for more than half of the growth of the world's population between 2019 and 2050 [3].

In the light of these conclusions it is interesting to look at which role developed countries with high urbanisation can play? Can a radical energy shift in developed countries energy systems change the whole picture and can these experiences be transferred to developing countries so that the result will be that the agreements in the Paris agreement can be fulfilled? Otherwise it will be difficult to reduce emissions since there is an ongoing strong increase in energy consumption in the developing countries.

2. Aims and Objectives

The aim of this paper is to discuss potentials and barriers for phasing out fossil energy on global and local level – Is it possible and on what time perspective? – Which can be the role of developed countries? -Which research is needed?

Objectives are to:

- Discuss trends for energy consumption and emissions on global level
- Discuss the implications of problems and conflicting goals in sustainable energy systems
- Analyse the Swedish energy system from formulated goals and achievements and discuss if solutions in Sweden are scalable to a higher level
- Discuss the need for an applied energy research agenda based on potentials and barriers

3. Global demand for Energy

The global energy mix is still depending mainly on fossil fuels. According to figure 1 the global share of fossil fuels is still around 80 %. The share of renewable energy sources is predicted to grow but this is just a loose prediction and different barriers might stop this development at a certain level. There is no natural law that this trend will continue to levels where the dominating energy sources are renewable and we cannot rely on just hope for this. Energy demand worldwide grew by 2.3% during 2018, its fastest pace this decade, an exceptional performance driven by a robust global economy and stronger heating and cooling needs in some regions which has turned the focus on the potentials of electricity as an energy carrier. The shift towards higher interest in electricity seems to be the future potential for renewable energy sources like, hydro, wind, and solar PV.
According to International Energy Agency In their New Policies Scenario (where new policies are implemented) [4] global primary energy demand grows by over a quarter between today and 2040 (Figure 1). The overarching structural trends that shape demand are population growth, urbanisation and economic growth. According to this scenario the use of fossil fuels will increase although also renewable energy sources increase. There are signs that in some important countries like China the use of natural gas will grow at the expense of coal but the share of renewables is still insignificant.

			New Policies	
	2000	2017	2025	2040
Coal	2 308	3 750	3 768	3 809
Oil	3 665	4 435	4 754	4 894
Gas	2 071	3 107	3 539	4 436
Nuclear	675	688	805	971
Renewables	662	1 334	1 855	3 014
Hydro	225	353	415	531
Modern bioenergy	377	727	924	1 260
Other	60	254	516	1 223
Solid biomass	646	658	666	591
Total	**10 027**	**13 972**	**15 388**	**17 715**
Fossil fuel share	*80%*	*81%*	*78%*	*74%*
CO_2 emissions (Gt)	**23.1**	**32.6**	**33.9**	**35.9**

Figure 1: World primary energy demand by fuel for New Policies Scenario [4]
Notes: Mtoe = million tonnes of oil equivalent; Gt = gigatonnes. Solid biomass includes its traditional use in three-stone fires and in improved cookstoves.

4. Energy systems and Sustainability

4.1 What is a sustainable energy system?

The concepts of sustainable development suggest that development should be in some way towards higher states of sustainability. The problem related to sustainability is that it contains conflicting goals. Does it imply economic growth and if so, where should the balance lie between economic growth, poverty reduction and environmental protection e.g. minimizing emissions of GHG which is actually just one effect among many? All these conflicting goals can easily be found in the UN 2030 SDGs. Maybe an even more important question is who should decide how to make priorities among the goals? For companies and most organisations, growth is desirable and when it comes to several frameworks for sustainability, the central idea is to decouple economic growth and environmental degradation often expressed as emissions of GHGs. This usually implies a target of continuing economic growth with less consumption of energy and materials. Some researchers argue that this kind of "sustainable development" cannot be achieved with existing economic growth models. The latter argument is in line with a doubt if ecological modernisation is possible [10]. Can we handle the problems of rising population and consumption by technology development? We can only reflect over the fact that if the rich economies grow at annual rate of 3% until 2070, and by that stage the emerging economies have attained similarly high living standards – which seems to be the aim of the UN global development agenda, the total world economic output and impact could be 60 times larger than it is today. It is also important to consider that it is more difficult to change an urban development which is socially and economically declining. Cities and regions which are in a phase of growth always have more choices than these declining.

The discussion around growth models is an active and important on-going discourse beyond the scope of this paper. Changing life styles and consumption patterns can only grow out from a bottom-up perspective in democratic countries and these changes will occur at different times in different cultures and developing states and cannot easily be controlled or predicted. The complexity around defining a long-term sustainable energy system depend mainly on the conflicts between different goals. Important conflicting goals are:

- Affordability of energy
  The costs of solar PV and wind continue to fall, but all energy sources can in some way be regarded as having subsidies, which makes the total picture complex. Taxes on fossil fuels can create serious inequities between different population groups and raise unrest as we have seen in France lately.
- Reliability
  Energy systems have to deliver energy in a predictable way with regard also to unforeseen events on local, national, and global scale Environmental impacts on local and global scale.
- Environmental impacts
  After several flat years, global energy-related carbon dioxide (CO2) emissions are rising, far from a trajectory consistent with climate goals in the Paris agreement. Energy-related air pollution also continues to result in millions of premature deaths each year

The conflicts between these goals cannot be resolved with scientific methods although such methods should reveal transparent facts which could be used in decision processes involving different stakeholders. In many urban projects in the West, the emissions of GHG have become a central criterion for the overall development. However, one must accept that it is one criterion among others in a broad decision process in an urban context.

It is necessary to consider which basic criteria we should use to characterise more sustainable energy systems before we can start planning for these and compare different alternatives. We can use these criteria in decision processes to formulate targets for short, medium, and long-term planning. The specific choices should be taken in a broad democratic process on local level.

In many cases the definitions of sustainability or sustainable development are to general and too vague to serve as guidelines for the practical implementation of sustainable energy systems and we will not review all these kinds of definitions here.
What is needed are more hands-on criteria which can be used by planners in formulating goals for a sustainable urban energy system.

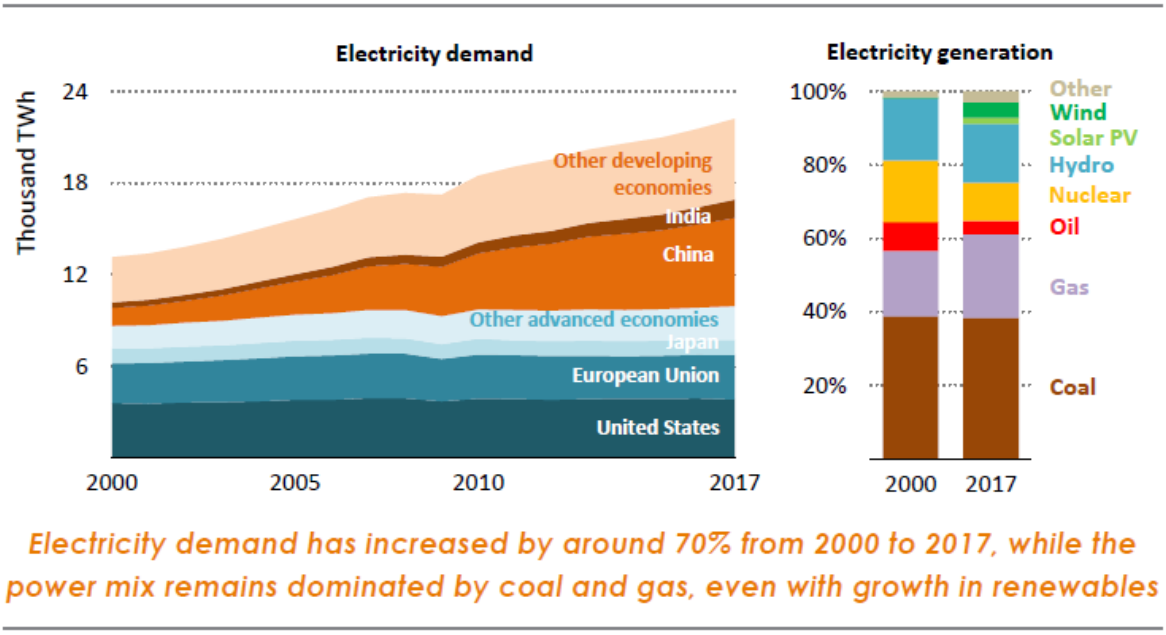
4.2 Environmental impacts of energy systems

The main focus concerning environmental impacts of energy systems has been on Green House Gas (GHG) emissions and Climate Change. However, the threats concerning the earth ecosystems are now turning out to be more complex than just GHG emissions from the use of fossil fuels,
In a recent report from IPBES it is stated that "Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide" (Díaz, 2019). In this report it is stated that "The direct drivers of change in nature with the largest global impact have been (starting with those with most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species. Most of the negative environmental effects of energy transformation are long term and highly uncertain, making long term planning and communication of risks difficult. One problem here is that there is no red line for environmental effects as it also is for social development. We cannot foresee the long-term consequences of environmental impacts as well as social changes. There is no scientific solution for Sustainable Development which can be developed by "experts". Sustainable Development involves many conflicting goals where different actors have different values concerning the priorities.
We have to accept the fact that the utilization of all primary energy sources is connected to social and ecological problems, but is needed to improve social conditions for people. Today's one-sided focus on one environmental aspect, climate change and GHG emissions, draws attention the very complex problem of sustainability. Evaluating energy systems has to include wide system boundaries in time and spaces as well as conflicting goals. We have to have more open eyes for these conflicts in order to handle them, not just put hope on change from and ideological standpoint.
One hope is that we can handle the problems of rising population and consumption by technology development. But can technology development really overcome the strong rebound effects from increasing population and consumption? We can only reflect over the fact that if the rich economies grow at annual rate of 3% until 2070, and by that stage the emerging economies have attained similarly high living standards – which seems to be the aim of the UN global development agenda, the total world economic output and impact could be 60 times larger than it is today. It is also important to consider that it is more difficult to change an urban development which is socially and economically declining. Cities and regions which are in a phase of growth always have more choices than these declining. It might very well be so that the developing countries will use more fossil fuels in the coming 50 years. In this case the only way to handle GHG emissions would be Carbon Capture and Storage. This will need huge investments and higher energy prices which make this solution difficult [5].

5. The role of electricity in the energy mix

Availability of electricity is essential for reducing poverty and improving health in developing countries. In developing countries, universal access to electricity remains elusive: nearly one billion people remain without access today. Electricity consumption globally increases at a faster pace than other energy vectors due to electrification of energy uses. We use the term consumption and in this we mean reducing quality. Electricity is an energy carrier and electricity have high quality and should therefore be used for high quality purposes. Most of the 2017 increase in global electricity consumption occurred in Asia. As in 2016, the electricity consumption growth in China, amid an

industrial recovery and despite strong energy efficiency improvements, contributed to more than half of the world electricity consumption rebound.



Note: TWh = terawatt-hours.

Figure 1: **Global electricity demand by region and generation by source, 2000-2017 [4]**

Demand for electricity continues to grow in developing economies whereas demand in advanced economies is flattening and in places is declining. However, there is a development towards electrification of the transport sector in developed countries that will change this trend. This trend is linked to the hope of increasing production from renewable sources but where is the limit for this trend? Comparing different sources for electricity it is important to separate installed effect and produced electricity. In China e.g. less than 20 % of installed effect from PV and wind is used for electricity consumption. It is very important now to study economies that tries to use more electricity from non-fossil fuels and see what experiences from this that can be drawn and what can be generalized. Which are the existing and future barriers? To investigate these issues we will look more closely into Sweden's ambitions to create a more sustainable energy system

6. The development of the Swedish energy system – A role model?

6.1 Background

Sweden has for a long time had high ambitions and high self-assurance for sustainable development and sustainable energy systems. This has been linked to the advanced planning of sustainable urban areas with a more holistic view of resource utilization [6]. It has been claimed that Sweden is one of very few countries which has decoupled GDP growth from increased CO2 emissions. This has been questioned because these figures are production based and emissions from production of imported goods are not included. Its often the case when evaluation sustainability of urban areas private consumption is omitted. This is partly because it is difficult to find data and partly because policies for changing people's consumption is politically sensitive.

According to a recent report from International Energy Agency (iea) [7], Sweden is leading the way towards a low-carbon economy. Today, it has the second-lowest carbon dioxide (CO2) emissions per gross domestic product (GDP) among the International Energy Agency (IEA) member countries (after Switzerland) and the second-lowest CO2 emissions per capita (after Mexico). In part, this follows from having the lowest share of fossil fuels in its primary energy supply among IEA members while remaining relatively energy-intensive. The report also concludes that Sweden's energy policy has been very successful to establish a sustainable energy system focused on energy efficiency and to switch from fossil fuels to domestic renewable energy.

A central question is off course why Sweden should be important when it comes to energy systems and the reduction of GHG emissions. Global CO2 emissions from fossil fuels increased by fourteen Sweden in 2018. Only China's increase accounted for four times Sweden's total CO2 emissions.

The Swedish government's ambition is however clear. In a recent debate article in a leading Swedish Journal our minister for international aid states that Sweden will be a leader in the implementation of Agenda 2030 - both at home and in terms of contributing to the global implementation of the agenda [8]. We are a pioneer, he states, in many areas, including climate and human rights. Sweden is and will be an international model for economic, social and environmental sustainability that takes into account the perspectives and human rights of people living in poverty.

The main argument from Swedish politician's is therefore that it is not the absolute values of Swedish emissions that are important, but that Sweden can act as a role model for transition of the energy system to being fossil fuel free.

6.2 The main goals for Sweden's energy system

Sweden has now one of the most ambitious goal to phase out fossil fuels in the near future. Sweden's overarching climate target is to reach net-zero emissions of greenhouse gases by 2045, followed by negative emissions. This long-term target is complemented by several intermediate milestone targets.

It is thus interesting to analyse this example in order to reveal problems and goal conflicts in this process and to develop realistic research agenda concerning barriers towards more long-time sustainable energy systems. There are still uncertainties of the main goal in Sweden since two concepts are used in the debate. One is *fossil fuel free energy mix* and the other *renewable energy mix*. Both have a focus on minimizing GHG emissions but the fossil fuel free energy mix accepts nuclear energy as a part of the mix. Nuclear energy is still a hot topic in Sweden already since the

referendum in 1980. The result from the referendum was not clear since it involved three different choices. Two of these alternatives got almost the same number of votes. These alternatives both states that nuclear power stations can continue to be used but the expansion of nuclear power would cease immediately and the remaining operational stations would be subject to stricter conditions and closed within ten years. Efforts would be made to reduce energy consumption and to increase renewable energy capacity. Uranium mining would be banned and efforts to prevent the proliferation of nuclear weapons would be enhanced.

During the last year, after the election for parliament 2018, several conservative parties and the liberal party have become more outspoken and now support the continuing development of nuclear energy. The party which strongly oppose on this is the green party (Miljöpartiet), which actually more or less grew out of the movement against nuclear power. Also “Centerpartiet” have been against the development of nuclear energy since many years. However, the costs for upgrading the existing nuclear power plants seems too high so gradually, in the short run, nuclear power will probably be phased out. Maintaining today's energy mix in Sweden will need the replacement of aging nuclear power plants with new nuclear power plants. This is a more long-term vision where e.g. GenIV reactors can be operating in 25 years from now. State-owned company Vattenfall is the majority owner of Ringhals and its four nuclear reactors. Vattenfall has stated business reasons as a reason for shutting down both reactors. Politicians charge such high energy taxes that it will not be profitable to maintain the two oldest units. Ringhals produces one fifth of all electricity used in Sweden. Shutting down tese reactors will mean that Sweden will reduce its exports of electricity and instead increasingly import electricity from our neighboring countries, such as Denmark and Germany, where coal power and natural gas are included. Therefore, greenhouse gas emissions will increase if these countries do not change their energy mix. Germany, one of the world’s biggest consumers of coal, will shut down all 84 of its coal-fired power plants over the next 19 years to meet its international commitments in the fight against climate change, a government commission reported recently. The announcement marked a significant shift for Europe’s largest country — a nation that had long been a leader on cutting CO2 emissions before turning into a laggard in recent years and badly missing its reduction targets. Coal plants account for 40% of Germany’s electricity, itself a reduction from recent years when coal dominated power production. The remaining question is where Germany and other EU countries should get their electricity when several countries, including Sweden, lower their capacity of fossil fuel free electricity.

According to decisions at the EU level, at least 32 per cent of the energy in the EU will come from renewable sources in 2030. At the same time, energy efficiency - how much saved compared to previous forecasts - should be up to 32.5 percent. Recently EU failed to adopt a goal to become climate-neutral EU in 2050. According to several sources, opposition to a climate-neutral EU in 2050 came mainly from Poland, but also the Czech Republic, Hungary and - somewhat more unexpectedly - from Estonia.

As a starting point Sweden has relatively low carbon dioxide emissions per capita compared to other OECD countries. A decisive reason is that electricity production in Sweden is completely dominated by carbon dioxide-free hydropower and nuclear power. In addition, the entire Swedish energy system has increasingly abandoned the use of fossil fuels.

Compared to the EU level Sweden has adopted more ambitious levels for reduction of the use of fossil fuels. Energy agreement from 2016 between 5 parties holding a majority in the parliament. This agreement includes:

- Target of 100% renewable electricity production in 2040
- Goal that Sweden should not have any net GHG emissions in 2045

- The nuclear power interruption is extended by allowing new buildings to be built in existing locations within the limits of a maximum of ten reactors
- Government support for nuclear power in the form of subsidies will not be introduced
- The tax on thermal power is phased out gradually over a two-year period starting in 2017
- The transmission capacity within Sweden will increase

The road toward reaching these goals however seems winding.

6.3 Swedish GHG emissions – Looking forward

In a recent report from the Swedish Climate Policy Council it is stated that since 1990, Sweden's greenhouse gas emissions have decreased 26%. This reduction mainly took place between 2003 and 2014. Thereafter the rate of reduction slowed, and 2017 was the third consecutive year in which emissions decreased less than 1%. This rate is far too slow to be in line with the climate goals, except for the upcoming 2020 target. The rate of reduction would need to accelerate to between 5% and 8% each year to meet future targets. A conclusion is that transitioning society to net-zero emissions by 2045 requires a fundamental systemic change and a high rate of progress throughout society.

Choice of system boundaries play an important role concerning emissions and possibilities to control the emissions. If a consumption-based model would be used the emissions would be higher due to import of goods from other countries.

As in many other countries a lot of hope is put on electrification in both the transport sector and in industry. This is an obvious shift from earlier policies in Sweden and a sign of the often-short sighted visions for the future. When the internationally renowned city district Hammarby Sjöstad [6] started to be developed 20 years ago one goals was to reduce the use of electricity as much as possible. Instead district heating was favoured. The main focus then was more on local environmental protection and not on GHG emissions. What will be the main goal in 20 years? The system and planning must be flexible for shifting goals over time.

Swedish Energy Agency has recently issued a report where scenarios have been developed for electricity from renewable energy sources [9]. One conclusion is that in 2040, all electricity can be renewable, even taking into account increased electricity use and nuclear power less energy from nuclear power. However, a system with a lot of solar power and cogeneration may need support. Perhaps support is also needed for new technology that can handle the transition to an electrical system with greater variation, since wind power is only produced when it blows and solar power when the sun shines. But only technology is not enough. More variable price is also needed. In all scenarios, it is concluded that the price signal can control flexibility and contribute with controllable power. In Sweden hydropower is produced mainly in the north. Then the price signal can make it interesting to put activities with great electricity usage in the north, such as server halls for example.

The conclusion for Sweden is that the political ambitions to be in the forefront in reducing GHG emissions seems to jeopardize the ability to support the metropolitan areas with electricity and to support economic development. Sweden will need a wider system view with greater awareness of conflicting goals in developing sustainable energy systems.

7. Main challenges for Sweden

A central problem in the Swedish planning of the future energy system is that its short-sighted and has focus mainly on reduction of GHG on national level. In sustainable development one has also to handle social and economic goals on national and global level.

The Swedish Climate Policy Council finds that the present transport policy goals and their implementation counteract the climate targets. The plans for achieving the transport sector's climate targets are unclear, both within the government and on the government agency level, as is the division of responsibilities. Sweden's infrastructure is being planned not around the goal of achieving the climate targets, but on forecasts of increased road traffic that are not in line with the 2030 target. The order of priorities for infrastructure investments – the so-called four-step principle – is not used in practice. The greater potential of cities to obtain more efficient transport, such as pedestrian, bicycle and public transport, is not being fully leveraged.

What the Council actually formulates is a recommendation to include the effects on the climate goals in all impact assessments in public inquiries and in government bills and proposals. In addition, prior to implementing new policy instruments, monitoring and evaluation plans should be created to ensure high levels of climate benefit and cost efficiency. This is in clear words is that the goal that Sweden should not have any net GHG emissions in 2045 should overrun all other goals. This is highly problematic because Sweden is not an isolated part of the world.

The main goal for the power system in Sweden should be to deliver safe and reliable electricity to an economy which is growing. The problem here is that the government favours electricity for all sectors including industry and transport, but at the same time reduce the possibilities for the energy system to deliver this. If Sweden close down nuclear reactors it will be more dependent on the hydropower which is situated in the north. Also, wind power is increased but wind is variable.
The fact that more and more people are choosing to move to our cities places high demands on our future electricity supply. This, together with the increased electrification of industry and transport, means that the electricity grid capacity in Sweden needs to be expanded rapidly. This situation will put stress on the transmissions system which is already under stress.

The mentioned digitalisation, electric car boom, continued urbanization, increased construction of housing from new subway lines, fossil-free steel production, electric aircraft and electric vessels, all have one thing in common: it requires a stable and increasing supply of electricity. But how should we be able to increase electricity generation and at the same time switch to a renewable energy mix where nuclear power, which accounts for almost 40 percent of production, does not have a part? This equation can be difficult to get together, especially as it is far from certain that Sweden can import all the electricity we need at the same time as the turmoil rises for future dry periods in the paths of climate change with water scarcity in the hydroelectric dams. This presupposes that there is an excess of electricity in neighbouring countries.

The solutions can be found in:

- Reducing peak effects in consumption utilizing e.g. pricing mechanisms
- Distributed energy production systems. This is however counteracted through e.g. and increase tax for CHP plants using waste based on that pert of the waste is coming from non-renewable sources. The CHP company Stockholm Exergi recently announced that the production of electricity from cogeneration is no longer economically sustainable, and that they will need to minimize energy production. The decision means that approximately 500

GWh of electricity that Stockholm has so far been able to rely on will disappear. The already strained power situation for the capital then drastically deteriorates.

- Higher capacity of the national grid system which involves long term investments

Locally produced power is essential for the supply of electricity in the southern parts of Sweden. The problem is not primarily about a lack of electricity in the country as a whole, but about network capacity shortages - difficulties in transporting the electricity from where it is produced to the places that demand the most electricity, or in some cases too low capacity regionally in the cities. It is simply full in the cables that supply the big cities.

8. Conclusions for Sweden

The Swedish energy development is through the political coalition including the Green Party very much focused on reducing GHG and loosing other aspects of sustainable development, which in the end can jeopardize the ambitions with the phasing out of fossil fuels. The high immigration to Sweden has caused segregation and social unrest because of lack of affordable housing.

The one-sided focus on creating a more or less renewable energy system in a relative short time has created several problems in some sectors with examples given below.

Several electricity intensive companies are now planning to move their facilities from Sweden because the energy companies cannot guarantee a stable delivery of electricity. The energy company Ellevio recently warned they not be able to connect anyone who wants electricity. The main reason why the demand for electricity is increasing in Stockholm is that the city is growing. This means new neighbourhood's, more homes, kindergartens, schools, workplaces, expanded public transport, more water supply networks, road tunnels, hospital sites, and so on. Add to this a strong digitization development, new business establishments, electric car boom and electrification of industries - everything requires more access to electricity. And it goes fast; electrification permeates social development the coming years in Stockholm. Several municipalities in Sweden have been forced to refuse the establishment of server halls. Some time ago, a battery factory was rejected because the capacity in the electricity grid was not enough.

The highest proportion of fossil fuels is in the transport sector, but it is also the sector that has changed the fastest from fossil fuels to others in the last ten to fifteen years. The main reason is that biodiesel HVO has increased significantly in the market and accounts for more than half of the renewable energy use in the sector. At the same time the Green Party is putting forward a ban for diesel cars. This means ban on technology not on emissions. Higher taxes on gasoline and diesel has also created unrest among car owners similar to what has happened in France

An intensive debate has been taken place concerning emissions from aviation. Sweden has introduced a tax on domestic air traffic in order to reduce the emissions but the effect seems to be limited. Other factors like economy and currency rate seems to be more important. It is also so that international flights have considerable higher emissions than domestic flights and there are obvious problems to have national tax on these.

However, a general problem is that most of the ambitions in Sweden is directed towards reducing GHG emissions on a national level not taking into account the global level. A good example of this is

the intended expansion of the PREEM refinery north of Gothenburg. The project aims to convert heavy oil into cleaner forms of fuel, which would reduce the environmental impact from a global perspective. At the same time, carbon dioxide emissions from the refinery would increase and make the plant the one that emits the most carbon dioxide in Sweden. It would also mean that Sweden's climate target with regard to zero emissions would probably not be achieved.

9. The need for research in energy systems

Energy research has to have a focus on solving problems on different levels for converting our existing energy systems into more sustainable energy systems in the future.
The Swedish example show that this is a complex task were also global considerations have to be taken into account. One question is why a small country like Sweden should have very ambitious goals for reducing GHG emissions when the developing countries at the same time is increasing their emissions at a much larger scale. The main contribution the Swedish development can give is to reveal the problems connected to energy transitions to renewable energy or fossil free energy systems and to develop applied technologies

Some examples of important research questions found in the Swedish context are:

- Which are the specific conditions for developed countries in the EU like Sweden and what can be generalized to other developed and developing countries?
- Which are the effects of short-term political policy decisions and goals on the long-term strategies for energy systems?
- Short- and long-term scenarios of energy systems based on rigorous LCA studies including technology development
- Solutions for avoiding effect shortages like price mechanisms, locations of energy users, new fast response production systems to supply power e.g. gas turbines using biogas or natural gas.
- How to handle conflicting goals in sustainable development of energy systems e.g. GHG emissions and biodiversity and economic growth and social development?

10. Concluding discussions

Despite international agreement to reduce the use of fossil fuels and to reduce GHG emissions the existing trends show something else. EIA (The U.S. Energy Information Administration), has projected that the worldwide energy consumption will grow by 53% between 2008 and 2035. The UN released in 2015 its Sustainable Development 2030 goals aiming primarily to reduce poverty on a global level. Embedded in the strategies to achieve the goals are high urbanisation rates and high annual economic growth (7 %) in emerging economies. It seems more and more obvious that the transition to more energy- and resource-efficient cities will be gradual and take longer time than expected. We will have the correct answer when the UN 2030 SDGs is presenting the results, but then it might be too late. It is also clear that transitions have to be anchored in a local context at the urban level where all key actors take part in the planning process. Urban systems are examples of very complex systems and the study of complex systems is about understanding indirect, sometimes unwanted effects. Problems that are difficult to solve are often hard to understand because causes and effects are not always obviously related. Pushing on a complex system "here" often has effects "over there"

Sweden has very ambitious goals to reduce GHG emissions. However, the path towards the goals seems very winding. In 2018 the emissions increased even when using a production-based calculation. There are still uncertainties of the main goal in Sweden since two concepts are used in the debate. One is fossil fuel free energy mix and the other renewable energy mix. Both have a focus

on minimizing GHG emissions but the fossil fuel free energy mix accepts nuclear energy as a part of the mix. One of the most difficult targets is to reduce GHG emissions in the transport sector. Here we can find clear examples of conflicting goals and short- and long-term targets. Biofuels can reduce the GHG emissions but will have negative effects of biodiversity and food production. Attempts to ban diesel cars will reduce the potentials for using biofuels in the traffic sector.

REFERENCES

1. UN, *Transforming our World - THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT*, in *A/RES/70/1*. 2015.
2. FAO. *THE STATE OF FOOD SECURITY AND NUTRITION IN THE WORLD* 2017; Available from: http://www.fao.org/state-of-food-security-nutrition/en/.
3. United Nations, D.o.E.a.S.A., Population Division, *World Population Prospects 2019: Highlights (ST/ESA/SER.A/423)*, D.o.S.a.E. Affairs, Editor. 2019.
4. IEA, *World Energy Outlook 2018*. 2018.
5. Wennersten, R., Q. Sun, and H. Li, *The future potential for Carbon Capture and Storage in climate change mitigation – an overview from perspectives of technology, economy and risk.* Journal of Cleaner Production, 2014.
6. Wennersten, R. and H. Liu, *HAMMARBY SJÖSTAD – A unique Sustainability Project in Stockholm*, in *ISOCARP · REVIEW 10 - WATER AND CITIES - MANAGING A VITAL RELATIONSHIP*. 2014.
7. Agency, I.E., *ENERGY POLICIES OF IEA COUNTRIES - Sweden 2019 Review*. 2019.
8. Eriksson, P., *We shpould be a leader for Agenda 2030 (In Swedish).* Svenska Dagbladet, 2019-07-27.