Coupling of energy sectors is a key to an efficient transition to a renewable energy supply

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FINANCE AND OWNERSHIP

COUPLING OF ENERGY SECTORS IS A KEY TO AN EFFICIENT TRANSITION TO A RENEWABLE ENERGY SUPPLY

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In order to reach an energy system based on renewable and sustainable resources in an efficient way, we need to transform our energy systems to allow fluctuating renewables to replace fuel consumption. This can be done through a coupling of the main energy consuming sectors via supply and conversion technology that links the production from fluctuating renewables to demands across sectors to reduce the need for fuel. Here we take a look at the effect on the whole energy system as 25%, 50% and 100% renewable electricity is introduced.

THE NEED TO TRANSFORM THE ENERGY SECTORS

Today, electricity, heating and transport demands are generally, on the global scale, covered through combustion of fuels and are generally seen as independent. These fuels have a number of environmental, social and economic consequences, such as climate change, pollution of water, soil and air, resource depletion etc., and it seems obvious that this is not a sustainable path to continue on.

The reduction of fuel consumption is important whether it is fossil or bio fuels. Fossil fuels have their issues, where carbon emissions is the biggest, but there are also issues in relation to bioenergy consumption. Bioenergy is a limited resource, and even though there is some discussion on how much of this potential can be used for energy purposes in a sustainable way, there is a general consensus on the fact that the resources are not enough to replace today's consumption of fossil fuels one-to-one. So on the long term we should strive to reduce the fuel consumption of all energy sectors.

DEMONSTRATING ONE POSSIBLE TRANSFORMATION PATH

In this article, I would like to demonstrate the idea of how a gradual replacement of the energy conversion infrastructure, from the traditional single-sector technology to a multi-sector focus, can help the coupling of sectors and significantly improve the system's ability to integrate fluctuating renewables reducing fuel consumption. I use four simple illustrations of energy systems, each with the same demands but with different supply systems and primary energy input. Even though the figures are simple, the different efficiencies and the systems' abilities to integrate fluctuating renewables are based on thorough investigations, and the systems have been analysed using real demand and production profiles in the hourly simulation model EnergyPLAN.

Energy efficiency measures in buildings, industry and vehicles are not discussed in this article, but are important to consider in the planning of this transformation. Essentially, reducing the demands will cut the total need for energy input and reduce costs for the energy systems and further improve the benefit of the sector coupling. Hence, the discussion in this article will be equal or more valid also in this situation.

Figure's legend and explanation

Conversion unit — Supply / demand — Electricity — Heating — Fuel

The figures illustrate energy systems as primary energy input on the left side, conversion units in the middle and demands on the right side. The demands are the same in all the four figures, and the differences illustrate different ways of covering the same demands. The numbers for the "Transport" sector do not add up to 30 because these include efficiencies of different vehicle types to cover the transport demand. The difference is mainly between internal combustion engines and battery electric vehicles.

Figure 1. A traditional energy system where sectors are divided and all demands covered through the use of fuel.

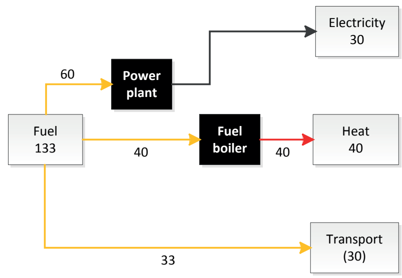


Figure 2. A combined heat and power (CHP) system that couples the heat and electricity sectors, where 25% of the total electricity demand can be covered by fluctuating renewables.

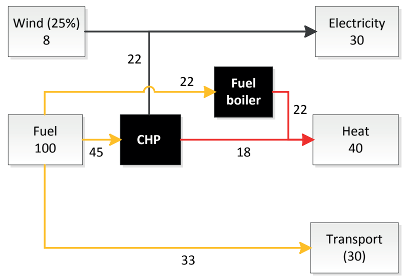


Figure 3. An integrated energy system where the heat and electricity sectors are coupled through both CHP and heat pumps, and where 50% of the total electricity demand can be covered by fluctuating renewables.

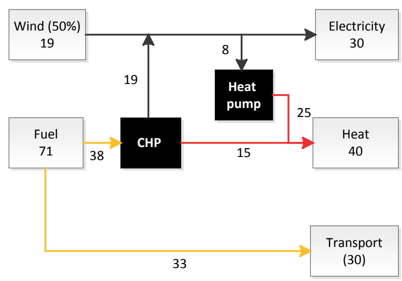
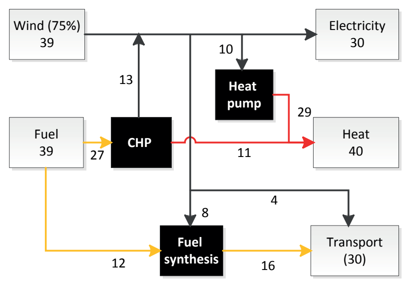


Figure 4. A smart energy system where the transport sector is coupled to the electricity sector through electric vehicles and synthetic fuels, and where 75% of the total electricity demand can be covered by fluctuating renewables.



FIRST STEPS TOWARDS SECTOR COUPLING

Traditionally, the different energy consuming sectors have been completely isolated from each other, which has led to the traditional energy system structure (see Figure 1). Here, fuel is used to cover all energy demands through single-sector conversion units, and the system consumes 133 units of fuel to cover the total demand of 100 units. The power plants producing the electricity may have a high efficiency when only looking at the electricity sector, but when considering that the excess heat from the process could have been used for other purposes, reducing the consumption of fuel elsewhere in the system, the efficiency doesn't seem that high any more.

SOME FLUCTUATION ELECTRICITY FROM WIND AND SOLAR

Figure 2 shows a system where combined heat and power (CHP) is implemented to improve the overall system efficiency through supplying the excess heat from the power production to cover heat demands. In some cases, this excess heat can cover heat demands in industrial processes, but in many cases, it will also require a district heating (DH) network to be in place. In systems with DH networks and CHP units, an investment in a relatively cheap thermal storage can support integration of fluctuating electricity up to about 25% of the demand in a cost-effective way. The thermal storage provides a flexibility for the CHP units to operate more independent of the heat demand, and more according to electricity demands, thereby being able to balance out some of the fluctuations from wind, solar PV, etc.

INCREASING ELECTRICITY PRODUCTION FROM FLUCTUATING SOURCES REQUIRES NEW DEMANDS

To reduce the fuel consumption further, integration of more fluctuation renewables is needed. However, this can be hard to do in a feasible way with only the conventional electricity demands. Therefore, an option can be to introduce electricity-to-heat through heat pumps or electric boilers for production of heat (see Figure 3). This can be relevant in buildings with individual heating systems, but particularly in areas covered with DH.

In DH networks, heat pumps can be operated more flexibly, for example by turning off the heat pump in times with very low production of wind power and instead supplying the heat from a centralised thermal storage. DH also enables utilisation of large-scale low temperature heat sources that would otherwise be lost, e.g. excess from industry, waste water treatment or hospitals. In individual buildings, the potential for operating a heat pump in a flexible way is lower because it has to deliver the heat when needed. But a heat pump is still more efficient than a fuel-based heat-only boiler if there is no DH network available.

Through all the steps, the power and CHP plants are producing gradually less electricity. In the transformation, their role is changing from being simply to deliver electricity to the electricity system to balancing the fluctuations of the renewable production. This will increase the requirements for the power and CHP plant's ability to regulate their production up and down.

COUPLING OF THE TRANSPORT SECTOR IN A 100% RENEWABLE ENERGY SYSTEM

The last step here is to couple the transport sector with the other sectors. This is achievable in a smart energy system, illustrated in Figure 4. This includes direct electrification (plug-in electric vehicles or electrified rail) of vehicles and fuel synthesis for production of liquid or gaseous fuel for combustion engines. The direct electrification of transport is important to expand as much as possible because this has a much higher energy efficiency than transport based on combustion engines. Not all transport can be covered with direct electrification though, so aviation, heavy ship and land freight may also in the future need some fuel. This need for fuel may be covered with electrofuels, which is a synthesis of 1) a carbon source, such as gasified biomass or CO2 emissions from CHP plants and 2) hydrogen from electrolysis using fluctuating electricity as the energy source. The fuel synthesis is not yet a well proven technology in large scale, so there are some uncertainties related to this still. However, it looks like a promising alternative for the transport sector to integrate fluctuating renewables, up to around 75% of the total electricity demand. In this system, it is possible to cover the demands with little fuel, and potentially cover all demands with 100% renewable energy within sustainable limits of bioenergy.

SUMMARY AND CONCLUSIONS

The three steps, from the traditional to the smart energy system, are able to reduce the need for fuel from 133 units to only 39 units, integrating additional 39 units of wind, in this particular case covering 100 units of demand. This can be achieved through an effort to couple the different energy sectors using flexible and efficient conversion units. The transition illustrated through the figures requires large changes, not only on the technological level but also in the regulatory frameworks and organisation of the energy sector to support such a transition. The core of this is that the current organisations and institutions are designed for (and by) a centralised energy system based on fuel consumption, whereas a smart energy system is much more decentralised in its components and organisations and its economy is based more on investments rather than consumption of fuel.

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