UNIVERSIDADE DE LISBOA

FACULDADE DE CIÊNCIAS

DEPARTAMENTO DE ENGENHARIA GEOGRÁFICA, GEOFÍSICA E ENERGIA

Energy Self-Consumption Policy, the future of distributed renewable generation?

Ricardo Valente Moura

Mestrado Integrado em Engenharia da Energia e do Ambiente

Dissertação orientada por:
Orientador: Miguel Centeno Brito (FCUL)
Co-orientadora: Maria João Rodrigues (IST)

2016

In loving memory of Vitor Moura

Acknowledgements

First off I would like to compliment my advisors for supporting this work that goes outside quantitative analysis we are familiar in engineering sciences, and challenging me to perform a more qualitative and conceptual analysis, noticing the importance of their guidance to attain a holistic approach to the theme. I thank Professor Miguel Centeno Brito for his constant availability, and creativity when approaching regulatory solutions and trends, a characteristic that is undoubtedly fundamental when envisioning innovation. And Maria João Rodrigues for her profound knowledge on energy policy trends, the energy system composition, funding and agents, that provided much needed clarity on the existing frameworks and best practices.

I would also like to thank my mother Paula Valente for always supporting my academic choices, for her positivity and unquestionable care. And off course for accepting to finance my education twice, either through tuitions or her taxes.

I could not forget my companion Teresa Miranda that has walked this journey with me, through all of its ups and downs, and also acknowledge all of my friends, who unavoidably and unwillingly have also become experts on energy policy for renewable energies.

Abstract

The traditional energy system is undergoing a fundamental change, with demand profile trends created by growth stagnation, energy efficiency and self-consumption challenging conventional utility's business model. At the same time political and structural transformations, such as the unbundling of the energy system itself, are redesigning stakeholders and how the whole system operates, symbolizing what could be the end of the term utility.

This work looks into the growing trend of self-consumption policies for distributed generation of renewable energy systems, motivated by the crossing of socket parity and the phasing out of renewables subsidies.

The work is divided into 4 main chapters, dedicated to:

- An international assessment and characterization of existing self-consumption regimes, where 39 countries and 63 states were reviewed;
- A proposal of operational and extended definitions to elucidate policy labelling, clarifying misconceptions around self-consumption, net-energy metering and net-energy billing terminologies;
- A concept analysis to review the role of these policy instruments in the future of the energy system, its impacts and constrains;
- And lastly, reflect on the potential of emerging concepts such as shared generation, peer-to-peer energy trading, under regulations such as virtual metering, as a regulatory enhancement of existing self-consumption policies.

The goal of this work is to provide key policy and regulatory considerations for devising more effective self-consumption policies. The future is still uncertain as policies and frameworks are yet to be consistent or stabilized, and a high degree of policy experimentalism is still present in these new grounds. We hope to portray a meaningful compilation of the main aspects regarding the concept, the typical implications and possible enhancements, to support regulators, the research community and decision makers in designing a path forward, that goes beyond utility scale renewable energy.

Key Words: Energy Policy; Self-Consumption; Net-Metering; Distributed Generation; Virtual Metering; Shared Generation; Peer-to-peer energy trading; Local network charges; Wheeling charges; Prosumer aggregation policy

Resumo

O *modus operandi* do sistema energético tradicional está sob uma transformação de paradigma, com as alterações no perfil de consumo potenciadas pela estagnação do consumo, eficiência energética e autoconsumo de energia a desafiar os modelos de negócio dos agentes convencionais. Em paralelo existem transformações politicas e estruturais, como o *unbundling* do sistema energético, redesenhando os *stakeholders* e o funcionamento do sistema.

Este trabalho investiga politicas de autoconsumo energético para produção de distribuída de energia renovável, uma tendência que ganha relevância com o atravessar da meta da paridade com a rede, e o abandono progressivo de subsídios à produção renovável.

O trabalho está dividido em 4 capítulos principais, dedicados a:

- Um levantamento internacional dos regimes de autoconsumo existentes, onde 39 países e 63 estados foram identificados;
- Uma proposta de definições operacionais e de relações entre tipologias diferentes, para clarificar terminologias e evitar utilizações erróneas de conceitos como autoconsumo, *net metering* e *net billing*;
- Uma análise de conceito para descrever o papel destes instrumentos políticos no futuro do sistema energético, os seus impactos e limitações.
- Por fim, uma reflexão do potencial de conceitos emergentes como *virtual metering*, e o seu potencial para reforçar as politicas de autoconsumo tradicionais.

O objetivo desta pesquisa é desenvolver considerações chave para o desenho de politicas de autoconsumo mais eficientes e adaptadas à realidade. O futuro destas politicas e regulamentações é ainda incerto, e estão longe de estabilizadas apresentando um grau de experimentalismo. Procurou-se compilar de forma compreensiva e fundamentada os aspetos principais do conceito, as implicações usuais e possíveis melhoramentos, para apoiar reguladores, a comunidade cientifica e decisores políticos no design e desenvolvimento de caminhos, que vão além da produção centralizada de energias renováveis.

Palavras-Chave: Politica energética, autoconsumo, net-metering; geração distribuída; autoconsumo remoto; geração partilhada; politicas de agregação de prosumers

Resumo alargado em português

Introdução

O *modus operandi* do sistema energético tradicional está sob uma transformação de paradigmas, com as alterações nos padrões de consumo potenciadas pela estagnação do consumo, eficiência energética e autoconsumo de energia a desafiar os modelos de negócio e financiamento dos agentes convencionais. Em paralelo existem transformações politicas e estruturais, como o *unbundling* do sistema energético, redesenhando os *stakeholders* e o funcionamento do sistema.

Este trabalho investiga politicas de autoconsumo energético para produção de distribuída de energia renovável, uma tendência que ganha relevância com o atravessar da meta da paridade com a rede, e o abandono progressivo dos subsídios à produção renovável. E mecanismos para catalisar essa difusão como *shared generation* e *peer-to-peer energy trading*.

O objetivo desta pesquisa é desenvolver considerações chave para o desenho de politicas de autoconsumo mais eficientes e adaptadas à realidade. O futuro destas politicas e regulamentações é ainda incerto, e estão longe de estabilizadas, apresentando um grau de experimentalismo. Procurou-se compilar de forma compreensiva e fundamentada os aspetos principais do conceito, as implicações usuais e possíveis melhoramentos, para apoiar reguladores, a comunidade cientifica e decisores políticos no design e desenvolvimento de novos enquadramentos, que vão além da produção centralizada de energias renováveis.

Regimes de autoconsumo no contexto internacional

Através de um levantamento internacional de iniciativas legislativas ou regulatórias, e literatura sobre a temática, formam identificados 39 países e 63 estados que já possibilitam este tipo de politica para a produção distribuída.

Os regimes apresentam divergências tanto a nível da nomenclatura utilizada, quer como na formulação e características regulatórias. As principais distinções identificadas foram:

- Mecanismos para remuneração da energia excedente, injetada na rede;
- Mecanismos de compensação da rede, para a porção exportada, ou autoconsumida;
- Limites de potência agregada, i.e. tetos máximos de produção adicional implementados em percentagem de penetração ou potência total agregada;
- Potência máxima por instalação, e restrições de dimensionamento;
- Tecnologias de produção permitidas na regulação.

Terminologia, definições e "etiquetagem" de politicas

O levantamento e a revisão bibliográfica permitiram identificar disparidades na escolha da terminologia para referir este género politico. As politicas de autoconsumo (ou *self-consumption policies*) aparecem frequentemente apresentadas como *net-metering* ou *net-billing*, nestes casos autoconsumo é visto como o ato de autoconsumir energia, ou como uma politica onde não existe remuneração do excedente (autoconsumo puro). Esta incoerência é prejudicial para a troca de experiências, análises comparadas e desenvolvimento de melhores práticas. Foi por esse motivo desenvolvida uma análise de conceito que apresente uma definição operacional para o autoconsumo, e clarifique as relações entre diferentes tipologias, de forma a promover e facilitar a comunicação sobre a temática.

A definição proposta está formulada da seguinte forma:

- O autoconsumo é um mecanismo regulatório através do qual é permitido a um ou mais consumidores de eletricidade produzir a sua própria energia, para abastecer parcialmente ou totalmente as suas necessidades. Estas sistemas podem estar conectados à rede para consumo ou exportação do excedente.

Impacto de politicas de autoconsumo no sistema energético

O conceito rompe com o funcionamento tradicional da rede no ultimo século, permitindo não só a produção descentralizada, como o usufruto direto da energia (ao contrário de politicas tradicionais nas energias renováveis, como as *feed-in tariffs*).

Os seus impactos são em parte devidos a esta produção distribuída, tipicamente do tipo não despachável, e os seus desafios e vantagens para a rede são semelhantes à restante penetração de energia renovável. No entanto as politicas de autoconsumo trazem também desafios adicionais para os vários agentes do setor da energia, sejam

- as comercializadoras forçadas a concorrer com este tipo de geração, diminuindo as receitas de venda de energia;
- os operadores de rede que vêm o seu financiamento diminuído, dado que a energia autoconsumida não paga uso da rede;
- os produtores vêm as receitas de mercado reduzidas nas horas de maior produção renovável;
- os consumidores passam a ter um papel ativo, incentivando o desenvolvimento de soluções e modelos de negócio inovadores.

A literatura não é consensual quanto ao resultado liquido destes impactos, dado que os estudos estão condicionados por características locais dos sistemas energéticos e as variáveis consideradas na metodologia. No entanto é possível retirarmos algumas conclusões gerais:

- Impacto financeiro do autoconsumo no sistema energético é principalmente influenciado pelos mecanismos de remuneração do excedente injetado na rede, pois em caso de subsidio este é geralmente compensado nas faturas de eletricidade dos consumidores;
- O impacto económico das características técnicas destes sistemas não é significativo, se por um lado requer um fortalecimento das redes de distribuição, por outro evita o investimento na rede de transporte, e diminui os preços de mercado através do chamado "*merit order effect*".

Estas duas conclusões podem guiar reguladores e decisores políticos no desenvolvimento de politicas de autoconsumo estáveis e sustentáveis.

Design de tarifas em autoconsumo, como remunerar excedentes e compensar a rede

É em torno destas duas características, identificadas no levantamento internacional, que roda a maior parte discussão regulatória em torno de politicas de autoconsumo, e onde surge a tensão entre os interesses de diferentes *stakeholders*. Os dois assuntos, remuneração de excedente, e compensação da rede, estão necessariamente correlacionados, particularmente tendo em atenção as conclusões do ponto anterior.

Olhando para o futuro, e tendo em conta as tendências para *phasing-out* de politicas subsidiadas em prol de uma integração no mercado, as necessidades de compensação fruto de subsidiação tenderão a diminuir, no entanto alguns autores levantam o risco de *cost-shiffting*, i.e. um aumento generalizado das tarifas de uso de rede como resposta, penalizando particularmente quem não dispõe de um sistema de autoconsumo. No entanto é reconhecido que existem tendências semelhantes como o aumento da eficiência energética, que induz o mesmo agravamento. Os reguladores devem repensar o design de tarifas de rede de uma forma holística e sustentável, e não através de taxas especificas sobre *prosumers,* que poderão contrair a difusão destes sistemas através de obstáculos económicos na integração de mercado e produção de pequena escala.

- É por isso defendido que as tarifas de uso de rede, recuperadas principalmente através uma formula volumétrica, terão que progressivamente passar a estruturas menos dependentes das vendas de energia, o chamado *energy unbundling* do financiamento;
- O resultado liquido do impacto de politicas de autoconsumo integradas no mercado é considerado positivo, inclusive levando alguns autores a defender a remuneração deste excedente tendo por base o seu beneficio económico para a rede (*value of solar tariffs*).

Otimização do rácio de autoconsumo, de forma a evitar a injeção na rede

Em cenários de integração de mercado, ou onde o excedente é remunerado abaixo do preço para o consumidor final, existe uma motivação implícita para otimizar a percentagem de energia autoconsumida. Este comportamento é benéfico quer para os consumidores aumentando a performance económica, quer para os operadores de rede que vêm a injeção variável na rede diminuída. No entanto as soluções para otimização (i.e. acumulação através de baterias, ou *demand-side management*) são ainda limitadas em potencial ou pouco eficientes em termos de custo. Surgem por isso alternativas como destino ou valorização do excedente de produção que não passam necessariamente por inovação tecnológica, estas alternativas aqui designadas de politicas de agregação de *prosumers* passam pela criação de mecanismos regulatórios que possibilitem modelos de negócio inovadores capazes de catalisar o autoconsumo.

Politicas de agregação de *prosumers*

As politicas de agregação de *prosumers* são complementares e fortalecem as politicas de autoconsumo tradicionais, permitindo um ambiente controlado para novos modelos de negócio. São mecanismos regulatórios que permitem:

1. A troca de energia entre *end-users*; apelidada de *peer-to-peer energy trading;*
2. Sistemas de produção partilhados entre várias entidades, ou *shared generation;*
3. Autoconsumir energia de sistemas *after-the-meter, "*fora" do ponto de consumo, usualmente chamado de v*irtual metering;*

Apesar de serem conceitos aparentemente disruptivos, existem precedentes que os sustentam, tendo em conta que os eletrões são todos iguais, a transferência virtual de energia é um conceito convencional, mas que até agora estava limitado a certos agentes, nomeadamente as comercializadoras. Outro exemplo são os chamados *power purchase agreements* (PPAs) um conceito semelhante já existente, mas limitado a consumidores de grande potência.

Existem exemplos de regulações e pilotos destes mecanismos em várias jurisdições. Nos EUA, dada a autonomia estatal, existem vários mecanismos distintos implementados, sumarizados em:

- *Aggregate net-metering* para transferência entre contadores de uma única entidade, tipicamente em propriedades contiguas.
- *Tenant aggregation*, ou *neighboohood net-metering*, onde a transferência acontece entre entidades distintas, que se encontrem dentro de uma determinada distancia, considerada como *on-site*.
- *Community Solar Gardens*, instalações de produção partilhada onde a energia produzia é distribuído entre várias entidades.

Existe ainda um mecanismo que engloba todos os conceitos anteriores, e permite a transferência de energia entre pontos a uma maior distância, este é apelidado de *virtual net-metering*, existe em 11 estados americanos, no Brasil e no estado de Israel.

Todos estes mecanismos foram, no entanto, desenvolvidos num contexto de autoconsumo com *net-energy metering*, neste contexto usualmente os serviços de rede não são compensados, facilitando a transferência. Para regular estes mecanismos fora deste regime, é necessário estabelecer uma compensação da rede pela transferência de energia entre pontos, quando considerados *off-site*. Tal pode ser feito através das tarifas de uso da rede tradicionais, não obstante, é usualmente argumentado que se esta transferência é local deveria refletir a redução de custos proporcionada ao operador da rede.

- Na Austrália foi simulado um sistema de troca local de energia (*local energy trading*) que estuda a sua implementação com 3 tipos de tarifa de uso de rede, uma standard, e duas com diferentes níveis de "desconto";
- Uma experiência semelhante foi desenvolvida no Reino Unido, onde uma empresa de software de gestão de energia (Open Utility) em conjunto com uma comercializadora "verde" (Green Energy), desafiaram o operador de rede (OFGEM) a realizar um piloto de um mercado local de energia. Estabelecendo uma plataforma onde produtores e consumidores se podem inscrever para vender ou comprar energia. A experiencia de 6 meses foi bem-sucedida e será implementada oficialmente.

A procura por estes modelos de negócio disruptivos, onde o consumidor passa ser um participante ativo, tem levado empresas e organizações a desenvolverem soluções, mesmo na ausência de regulamentações. As oportunidades abertas não estão só acessíveis aos agentes tradicionais, como as comercializadoras, agentes não convencionais como fabricantes de equipamentos e softwares (e.g. Open Utility) têm conseguido um papel ativo nestas inovações.

- A Sonnenbatterie é um exemplo interessante, inicialmente era uma empresa fabricante de sistemas de acumulação inteligente, que explorou uma oportunidade para construção de uma plataforma de troca de energia no mercado alemão, constituindo-se para tal como uma comercializadora oficial.

A ausência de politicas de agregação de *prosumers* não é um impedimento para o desenvolvimento de iniciativas dentro do género, no entanto um ambiente regulatório especifico, e a existência de tarifas de rede apropriadas, permitem o desenvolvimento saudável e previsível de inovação no sistema energético. Estas iniciativas podem trazer vantagens quando comparadas com politicas de autoconsumo tradicionais, tais como:

- Expansão do mercado potencial de adoção;
- Efeitos de economia de escala;
- Melhorar o *load matching* graças à suavização do perfil agregado;
- Alternativas na valorização do excedente;
- Qualidade, localização e visibilidade da interconexão.

Contents

Figure index

Table index

Chapter 1 - Introduction and research proposal

1.1 Overview

1.1.1 State of the art

The work conducted focuses on renewable energy (RE) generation policies for electricity production. This sector has historically shown fluctuations in capacity increase, although it has globally always presented a positive annual capacity growth. The power sector showed the most significant renewable growth in 2014, out of the three sectors: power; heating and transport. According to the Renewable Energy Network for the 21st Century (REN21) the global renewable power capacity reached an estimated 1712 GW at year's end, an increase of 8.5% over 2013. Hydropower was actually the push down on this average increase, with only 3,6% increase to approximately 1055 GW, while other renewables collectively grew nearly 18% to an estimated total approaching 660 GW. Globally, wind and solar PV each saw record capacity additions, each surpassing hydropower and together they accounted for more than 90% of non-hydro installations in 2014[1]. These two non-dispatchable RE technologies are considered the most promising for renewable energy self-consumption systems due to resource abundance.

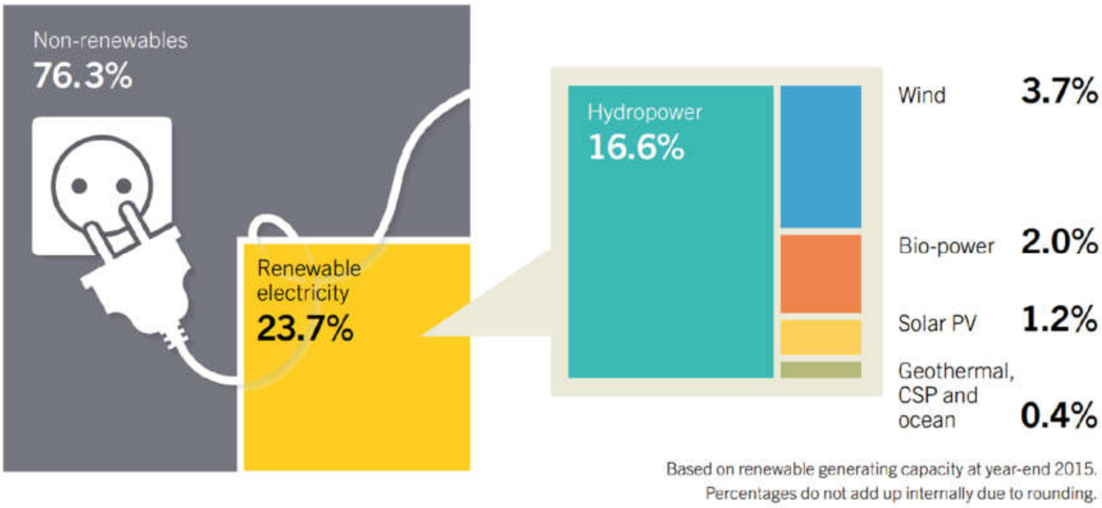


Figure 1 - Renewable Energy Share of Global Electricity Production (Source: REN21 GSR 2016)

In 2014 renewables represented approximately 58,5% of net additions to global power capacity exceeding conventional technologies for the first time, in 2015 this value raised to an impressive 90% of new production capacity, with wind power, solar PV, and hydro power dominating the market. By the year's end, renewables comprised an estimated 27,7% of the world's power generating capacity, in terms of energy volume, we see from Figure 1, it represents an estimated 23,7% of global electricity, while non hydro renewable electricity only represents 6,3% of total production[2].

Distributed generation (DG) has been an intrinsic characteristic of renewable generation due to the widespread resources and scalability, it has also allowed a transformation to traditional energy generation ownership models. This can be seen in the case of Germany for instance, in 2010, 51% of the installed renewable power generation capacity of 53 TW was owned by private persons and farmers, 7% by smaller utilities and only 6.5% by the four large power companies. Concerning PV, the figures were even more impressive with the four large utilities owned only 0.2% of the capacity [3].

Wind power is acknowledged as the most mature non-dispatchable RE technology. It was the first to reach higher penetration levels, and to compete with conventional generation in terms of levelized cost of energy (LCOE), reaching grid parity in utility scale power plants [4]. In smaller scale applications on the other hand, such as those for the residential sector, wind energy benchmarks have not reached the same levels of performance. Small scale wind power plants failed to achieve a similar maturity as their high power counterparts, this is due mostly to a decreased resource profile potential at lower altitudes, as those of small scale applications, and system operational issues working at highly variable wind speeds and directions. Thus in lower generation power ranges it has been solar PV to reach breakthroughs in terms of RE deployment rates.

The solar PV market, represented in mainstream applications by silicon semiconductor technologies, has presented a stable double digit growth in global installed capacity for the last decade, as can be seen in figure 2. The global growth in the last decade from a mere 3,7GW to 177GW by late 2014 is an undeniable positive outcome. This sector features an average growth of more than 30% each year since 2005[5].

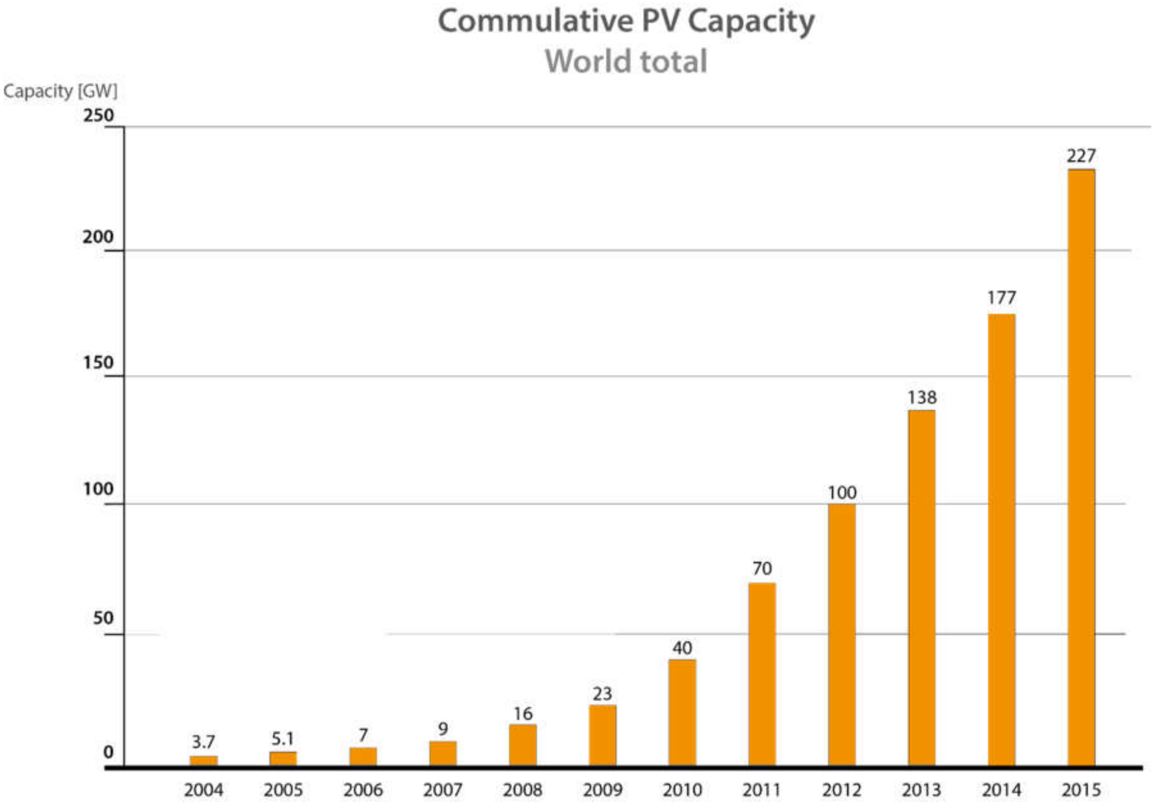


Figure 2 - PV Global Capacity (Source: adapted from REN21 GSR 2016)

Even though there are anomalies to this trend if we look into individual country profiles, these are mostly attributed to national conditions and unstable policies and regulations, PV system costs have reduced approximately 80% since 2009, and it is forecast to continue dropping by up to 59% util 2025[6]. At the moment the PV sector still accounts for less than 1,2% of the global power capacity for electricity generation. Although this number might not seem very impressive, PV technology is preforming above expectations in terms of its learning curve. In fact, this growth has even exceeded most projections by international agencies, such as the reference report World Energy Outlook form the International Energy Agency (IEA), and with the once considered extremely optimistic scenario from Greenpeace "Energy (R)evolution" being in fact one of the most accurate[7]. A key reason for these deviations was the assumption of an inadequate growth pattern for PV. The trend analysis assume linear growth, whereas history shows an exponential growth for the new renewable energy (RE) technologies[8].

Germany was still the leader in installed PV power in 2014, holding 22% of the total PV capacity (38,2GW), but in recent years they have been surpassed in additional installed power by China, Japan and the USA. In 2014, Asia implemented more than 50% of the total new installations.

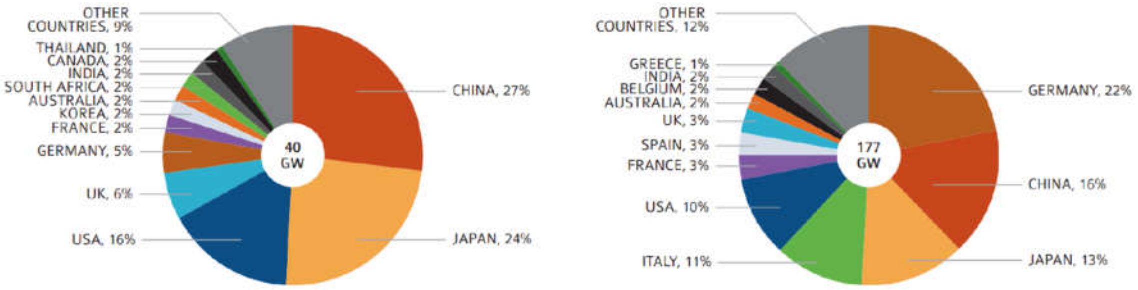


Figure 3 - Global PV market in 2014 (Left) Cumulative PV Capacity in 2014 (Source: IEA PVPS 2015)

This steady overall increase is due to different trends, but the rapid cost reduction in PV modules is one of the key economic drivers, the average price for a PV module has presented a four-fold reduction in cost over the last decade[5].

In Figure 4 we can see that the minimum price for residential PV modules has stabilized since 2012, with even a slight increase in 2013, but followed by a new drop in 2014. The minimum reported price for PV module in 2014 was in China with a cost of 0,61 USD/W[5].

Furthermore, we can see that the whole system price, which incorporates additional equipment (i.e. inverter) and installation/soft costs, has continued to decline. Since it represents a more accurate deployment cost the fact that it continues to decrease is a positive signal for residential PV.

Another important issue for the rapid development of PV power is its scalability, affordable PV system can exist in the range of watt to gigawatt proportions. This essential characteristic makes Si-PV the most mature technology for residential scale generation, and closely connected to the rise of the prosumer movement and is usually presented as the primary technology for RE self-consumption at the present moment. Even though residential installations are typically of a small scale, the sheer number makes them an important contributor for the overall deployment of PV and business opportunities.

An important challenge for the residential sector in self-consumption regimes is to guarantee load matching between demand and self-generation. Due to the mismatch of sunshine hours and residential electricity consumption, households have difficulties using more than 30% of their 'rooftop' electricity production for their own needs, unless they make supplementary investments in storage or demand-side management technologies. Industry applications on the other hand have typically a more adequate load profile and can reach self-consumption ratios of up to 100%[5].

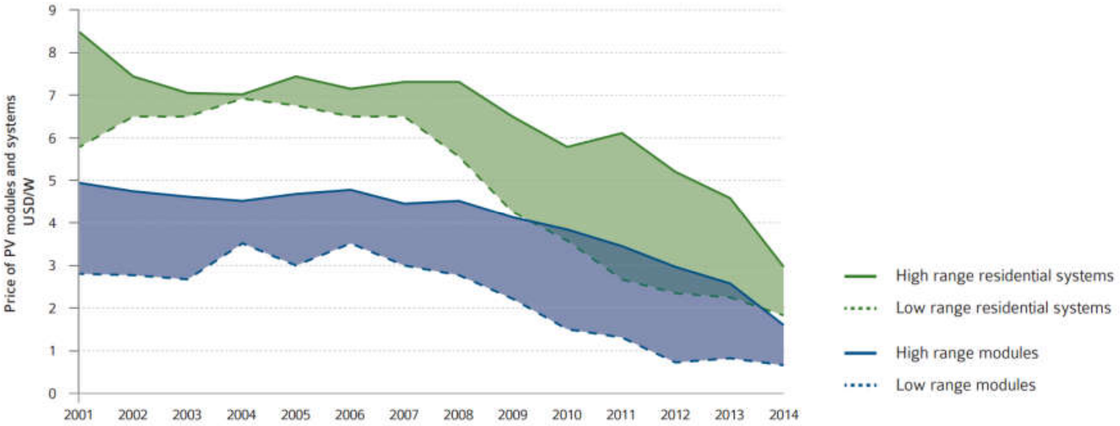


Figure 4 - Evolution of PV modules and Small Scale System Prices (Source: IEA PVPS 2015)

1.1.2 State of the regulation

To start a discussion on public policies for self-consumption, it is crucial to have a good overview of the generic form in which policy instruments might exist and be developed. There are several theories on how to classify public policy instruments, by public policy instruments we refer to a set of techniques by which governmental authorities wield their power in attempting to ensure, support, effect or prevent a certain social change [9]. Nonetheless, for the case of RE policies and the purpose of this work, the proposition made by Charles W. Anderson, in the textbook Statecraft*,* is seemingly appropriate:

"When we face a public problem, there are really only four sorts of things that we can do about it. Which we will decide to employ depends largely on how much freedom and how much compulsion we think as appropriate in the particular situations.

1. **Market mechanisms**; We can let the outcome depend on what individuals decide to do, without any interference or direction from government.
2. **Structured options**; We can create government programs...that individuals are free to use or not as they see fit.
3. **Biased options***;* We can devise incentives and deterrents, so that individuals will be guided, voluntarily, toward the desired ends of public policy.
4. **Regulation**; We can directly control, setting up constraints and imperatives for individual action, backed by the coercive powers of government."

Examples of RE policy deployed can be found within any one of these classifications, or a combination of the above, these typologies are described within Anderson's "choice vs resource approach", which divides public policy into two primary options, intervention and nonintervention. Freedom of choice, in this case to deploy renewable energy systems, is defined and delimited by statutes, rules, and regulations that derive from this primary question (Anderson 1977: 56-71). Nonintervention doesn't necessarily correspond to lack of regulatory provisions, but a neutral attitude from the government in terms creating contains or incentives towards a behavior or technology. There are still examples of complete absence of regulatory provision for any type of renewable energy, however the absence of provision however does not mean an absence of RE. "Undeniably, Anderson's classification taps something important as far as government choices goes. Since Max Weber, the degree of compulsion to be used in a control situation has been heralded as the crucial issue in decisions on public policy. It is an indisputable strength in Anderson's typology that it pays heed to this idea"[9].

Yet Anderson's typology does create problems, one of which can particularly concern the topic of this research which is market mechanisms. Market mechanisms are equated with government noninterference in this theory, but "doing nothing" is not identical to leaving everything to the market. There are other alternatives to public intervention than markets, the most important of which are civil society and households. The importance of which will be evidenced in the last chapter of this work, on prosumer aggregation policies. Typical cases of civil society are the neighborhood, social networks, and voluntary associations, such communities fulfill numerous roles in every society. "They make cooperation on an informal basis possible outside the market and the households, and they provide the foundation for the emergence and maintenance of social norms"[9].

Figure 5 presents an adapted version of Anderson's approach that does deem nonintervention as identical to "market mechanisms" nor make market mechanisms a choice on a par with the government interventionist alternatives.

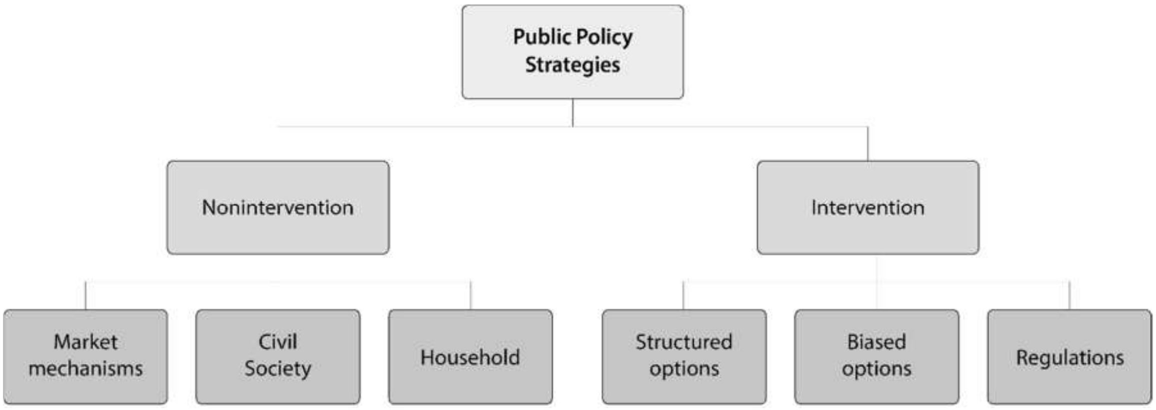


Figure 5 - The amended Anderson typology of basic policy choices (Source: Adapted from Statecraft, 1977)

Historically, renewable electricity policy has been motivated in part by the need to "close the gap" between the costs of renewable electricity and the costs of conventional fossil generation, what could be seen as a biased option public intervention. In this context feed-in tariffs (FiT), a policy mechanism that usually offers a long term contract setting a fixed price for generated electricity, represent the majority of the schemes in practice. However, with continuous cost reductions of PV systems, crucial questions emerged concerning how current policy frameworks might need to be adjusted or reimagined with the reach of grid parity and the need to market integration. It is thereby noticeable a transition from FiT to other regulatory schemes such as tenders, market premiums, self-consumption, that can decrease the level of public incentive, or simply tend to decline the revenue value in existing FiT models, in some cases with retroactive effects (i.e.. the case of Spain).

It is usual to implement an aggregate capacity limit or in other words the maximum global capacity for FiT schemes or other incentivized regimes. They are important in subsidized programs since the absence of these limits can lead to unstainable market growth, these phenomena are correlated with an imbalance between the level of the tariffs and the declining cost of technology, leading to artificial highly profitable investments. An example of the dangers of this imbalance was the market boom in Spain in 2008 and the consequent crash in the PV market, the government had envisioned 470 MW of additional power but the over-appealing investment return-on-investment led to an increment of 3000 MW. Therefore, it is also recommended to review and update incentive levels in a short regular basis, since even with a review period under a year Germany did not avoid a market boom in December 2011, where 3GW of PV were installed[5].

Tenders on the other hand are a fixed price arrangement similar to a power purchase agreement (PPA), contrary to FiTs tenders have a competitive basis, as the purchase tariff is set through a reverse auction mechanism. This mechanism is typical in big scale RE plants, and avoids the need to set a cap since the scale and number of permits for these installations are set by government institutions or utilities. Tenders have led to record contracts for utility scale PV and present a serious indicator of the gap closing towards wholesale grid parity, especially in emerging PV markets. With 5,85 to 6,13 USDcents/kWh results in the middle east (Dubai and Jordan respectively) and 7,5 to 8,75 USDcents/kWh in the Americas, Africa and Asia (Texas, South Africa, Brazil and India)[5].

Another follow-up policy for the phasing out of FiT are the feed-in premiums (FiP), what distinguishes them from traditional FiTs is that in this case the electricity is sold to the energy markets at wholesale market price, and a premium is paid on top of that price. This premium can be of a fixed value awarded on top of the market price, or a variable value to reach a certain fixed level with the sum of parts. This will help guarantee the investment's financially attractive, but also provide more tangible market signals. Also here, governments or utilities can potentially save some funds by avoiding the payment of the whole price set for PV electricity, public incentives in FiPs will only cover the difference between what the market is paying and the revenue level that was set by the government, this explains the terminology chosen by the UK to refer to these mechanisms, which are known as "contracts for difference". The European Union's guidelines increasingly suggest FiTs as not market compatible, because they led to "market distortions" in the past, it is suggested to phase out of these mechanisms in favor of FiPs which expose renewable energy sources to market signals[10].

All the policies above can present variations from jurisdiction to jurisdiction, and they are not the exclusive models for regulating grid-connected RE electricity, even though they are the most commonly practiced, from small roof-top installations to utility scale PV plants. One crucial factor separates the policies aforementioned from the ones that will be scrutinized throughout this work is that the first assume bulk RE generation is fed into the grid, rather than used primarily for local consumption as happens in self-consumption regimes, sometimes referred to as Net-Energy Metering

(NEM). The aim of this work is to look into policies that allow citizens to partially or totally consume the electricity produced by their RES directly, or self-consume as it will be referred hereon after. Self-consumption has the unique characteristic of allowing for grid-connected and off-grid configurations, together with full export configurations we can organize DG into three possible typologies of grid-interaction, as depicted in Figure 6.

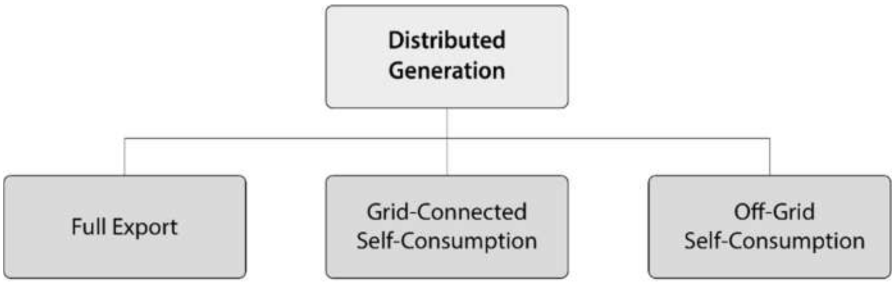


Figure 6 - Typology of Distributed Generation according to system-grid interaction. (Source: Author)

When self-consuming, these consumer-producers, or prosumers, can perceive a direct benefit by generating savings in electricity bills, and not solely by the revenues provided by a grid purchasing policy. Such policies are therefore denominated Self-Consumption policies. These models can still present subsidies or incentives, typically for instantaneous surplus generation, which is exported to the grid, but in certain regimes also to the whole electricity generated (the case of China and the UK). From Figure 7 we can see that only 3,7% of the worlds classic regulations where non-incentivized, versus a remaining 96,3% of subsidized RE Policies, and this fact has remained unchanged even though a decline of the subsidy levels can be seen in benchmark markets. We can also observe that FiTs maintain a significant dominance amongst the different policy approaches (58,6% occurrences in 2014). The decrease in FiT market shares, from 64,6% to 58,6%, can be seen as a sign of the phasing out of FiT policies. In 2014 only one new FiT legislation was adopted, in Egypt, even though it is still in practice in over 73 countries there is a tendency for lowering tariffs and phasing out of these mechanisms in some cases with retroactive effects[5].

Figure 7 - 2014 and Historical Market Incentives and Enablers (Left and Right respectively) (Source: IEA PVPS 2015)

However, there is yet to be a unanimous trend in policy evolution, Europe is now exploring self-consumption policies as an alternative to feed-in tariff policies, partially in order to address grid and market integration concerns. At the same time, other jurisdictions are exploring value based feed-in tariffs, such as the value of solar approach, as an alternative to net-metering policies, in order to avoid utility revenue erosion[11].

1.1.3 State of the compromise

The vast majority of countries worldwide have now renewable energy support policies or targets in place [2], the 21st conference of parties in Paris 2015(COP21) seems to bring a wider compromise with sustainability from both developed and developing countries. A total of 195 countries have agreed to limit global warming to below 2 degrees Celsius, through nationally determined contributions, and 147 of those contributions mentioned renewable energy.

This does not necessarily translate to an increased support of local distributed generation or self-consumption policy diffusion. The majority of policy instruments for RE are still through subsidies assuming a bulk export of generation, even though a slight increase of self-consumption regimes is observed. Therefore, it is not clear if the compromise with renewable generation is extended to a compromise with distributed self-generation such as residential self-consumption. Renewables can also be deployed through centralized, utility scale power plants, that while reducing energy related emissions, they fail to explore the opportunities to democratize access to the production sector, and diversify its agents.

If we look to developing countries, the contribution of centralized generation is typically superior to smaller distributed generation, in fact they have contributed to the leveling of the shares of both types of generation, which traditionally tended to a superior share of distributed generation.

Europe's energy policy is now focused towards the ambitious project of the Energy Union, which is strategically divided into 5 main areas: supply security, energy efficiency, integrated internal energy market, climate action and research and innovation. One could argue that all of these areas could relate to the topic of self-consumption and citizen participation in the energy transition. However, this does not translate to specific directives safeguarding the right to self-consume, even if it is commonly referred in the official political propaganda. In an Energy Union presentation video for example, we can see its vice-president Maroš Šefčovič refer that "(…) ultimately we will engage consumers into managing and even generating their own electricity." However, EU's proposition or directives have traditionally favored more "centralized" RE installations, such as tender mechanisms, and bulk export mechanisms such as FiTs and FiPs.

On the other hand there are also positive signs in recent guidelines suggesting that subsidies for mature renewable technologies should fade out after 2017, but that subsidies for small scale RES should be allowed (<1MW)[10]. Additionally, in February 2015, the European Commission published its new energy union strategy depicting a vision in which "citizens take ownership of the energy transition, benefit from new technologies to reduce their bills, participate actively in the market". And citizens seem to agree with this vision, when asked about their individual contribution to climate protection, 5% of Europeans replied that they already implemented renewable energy installations in their homes, according to a 2013 Eurobarometer survey[12].

1.1.4 Basic concepts

1.1.4.1 Distributed vs Centralized

Renewable energy has been the driving force to a paradigm change in how the electric grid and operators function. Historically, with the electrification of societies, the public grid evolved to a centralized configuration with a unilateral flow of electricity. High power generation plants would produce electricity that flows from the higher voltage lines of the transportation grid, then following the lower voltage distribution grid until it reached end users. The distributed nature of renewable energy sources and technologies made it accessible for small scale promoters and citizens to disrupt this kind of generation, allowing for decentralized typologies of generation systems, such as distributed generation (DG).

The most straightforward definition for distributed generation is that it is connected to a local distribution network system to which homes, offices, and small businesses are generally connected, while centralized energy is connected to the higher voltage of the transport network. DG is also often referred to as on-site generation, dispersed generation, embedded generation, decentralized generation, distributed generation. Many stakeholders consider distributed generation to be any generation connected at the distribution level, whether serving customer load, or merchant generation[13].

A more constraining definition describes DG "Energy generated at or near the point of use. (…) applications connected to low-and medium-voltage power lines with an average transport distance from several hundred meters up to around 100 kilometers"[7].

Even though decentralization can lead us to assume small scale power plants, they can have larger scale proportions (such as a MW size wind farm), several different distributed RE technologies are available, such as: solar photovoltaics, onshore wind turbines, run-of-river or small hydro power plants, bioenergy and geothermal power plants, and potentially near-shore ocean energy plants.

The scalability of these technologies (especially for PV) and abundance of free resource are two fundamental drivers to unlocking distributed generation and subsequently self-consumption systems.

1.1.4.2 Grid parity vs Socket parity

The theme of renewable energies achieving grid parity has hovered over renewable policies and technologies for the last decades. Grid parity is defined as generation technologies achieving a cost per energy unit that is equivalent to the energy cost of the energy acquired from the grid or traditional fossil fuel sources. This price comparison is made through the levelised cost of electricity (LCOE).

The levelised cost of electricity is the average cost of a megawatt hour produced by a given plant, including the fuels cost required to produce a MWh, but also the operating expenses (maintenance, taxes, etc) as well as the amortization of the investment. The LCOE of PV plants was decreased by a factor of five over the past years[14].

The definition of grid parity can have different interpretations that became more relevant with the crossing of this benchmark, one that includes taxes and grid charges in the energy price, and one that does not include these components but only wholesale energy cost plus the retailers' business margin.

Therefore, two types of grid parity can be distinguished:

- **Retail parity**, which is also known as socket parity. Retail parity is defined as the point at which the cost of generation from renewable energy systems is lower than the cost to purchase retail electricity from the grid, including taxes and grid charges[15];

- **Wholesale parity**, defined as the point after which the LCOE of the system is lower than the wholesale market price of conventional generating technologies, the retailers' business margin on energy price could also be incorporated.

These two terminologies will be used throughout this work to clarify the meaning of the term grid parity implied.

Although in the big picture renewables are still more expensive than conventional power generating technologies, the gap has narrowed significantly over the last decade. Utility scale renewables have proven to be wholesale competitive with new-built fossil fuel generation, depending on local context constrains[16].

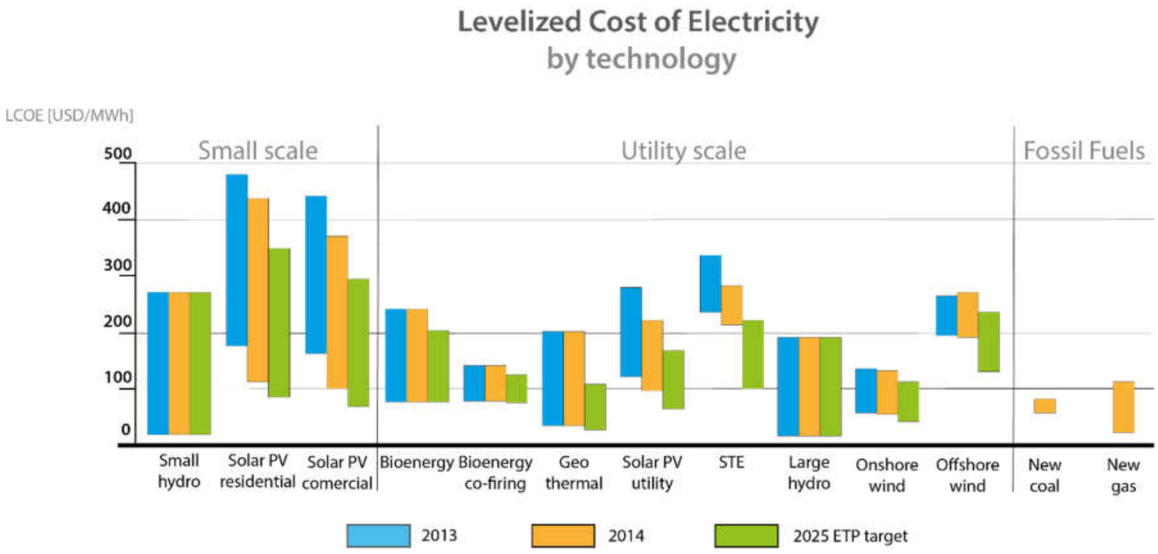


Figure 8 - Levelised Cost of Electricity (LCOE) (Source: adapted from IEA TCEP 2015)

As we can see in Figure 8 the LCOE of each technology can vary considerably. These discrepancies are mainly affected by the natural resources available, equipment and maintenance cost and assumed cost-of-capital[17]. Equipment cost can present high volatility that can be accounted to the importance of economies of scale, as we can see from the expected performance of utility scale versus small scale.

Retail parity has a particular importance for energy consumers, since if they can self-consume their own generation, it would not require the system to be wholesale competitive, but simply competitive with the full energy cost charged by their electricity retailers, generating energy savings proportional to the difference of values. “Self-consumption presupposes that the cost of producing PV electricity is cheaper (at the time of investment or during the lifetime of the PV system) than the price that the consumer pays for his electricity”[18].

A study by the Joint Research Center for the European Commission has concluded that on this basis the PV LCOE without subsidies is now below the residential electricity price for more than 79% of Europe's population[19].

In case where the LCOE remains higher than most other technologies, PV producers need monetary support: revenue schemes (FiT, Green Certificates, etc), tax incentives, direct subsidies, etc[14].

1.1.4.3 Rise of the prosumer

Prosumers: consumers who are also producers of their own electricity[20]. The prosumer concept is an emerging straightforward term gaining importance in the RE world.

PV prosumers are defined not only by the fact that they generate their own power, but also by their relationship with existing electricity providers (e.g. utilities). The relationships between prosumers and traditional utilities can take a range of forms, such as:

- **Grid defection**, Prosumers could cut ties with the existing utility system in order to live “off the grid” and supply 100% of their own electricity needs with PV, storage, and other technologies;

- **Self-consumption**, Prosumers could continue to purchase power from the grid, but reduce the amount purchased by using PV to supply a portion of their own electricity needs (and potentially get remunerated for any surplus generation that they may inject into the grid);

- **Commercial electricity production,** Prosumers could sell a large share of the power generated into the grid, while continuing to purchase electricity from the utility as well[11].

Prosumers and self-consumptions policies are inseparable notions; as prosumers are the agents regulated in a self-consumption policy.

There are two standard concepts that are fundamental to understand self-consumption systems:

- **The self-consumption ratio** (i.e. how much you consume from the RES total production, self-use);

- **The self-sufficiency ratio** (i.e. how much you consume from RES when compared to your whole consumption).

The self-consumption ratio can be increased by optimization strategies (refer to chapter 4.5.3), and is an important factor for the export remuneration issue, it is inversely proportional to grid injection. On the other hand, self-sufficiency accounts for what percentage of the whole consumption is self-generated. If optimization solutions are limited, increasing the self-consumption ratio might lead to decreasing the system size, which on the other hand decreases self-sufficiency. Figure 9 illustrates these concepts through two examples.

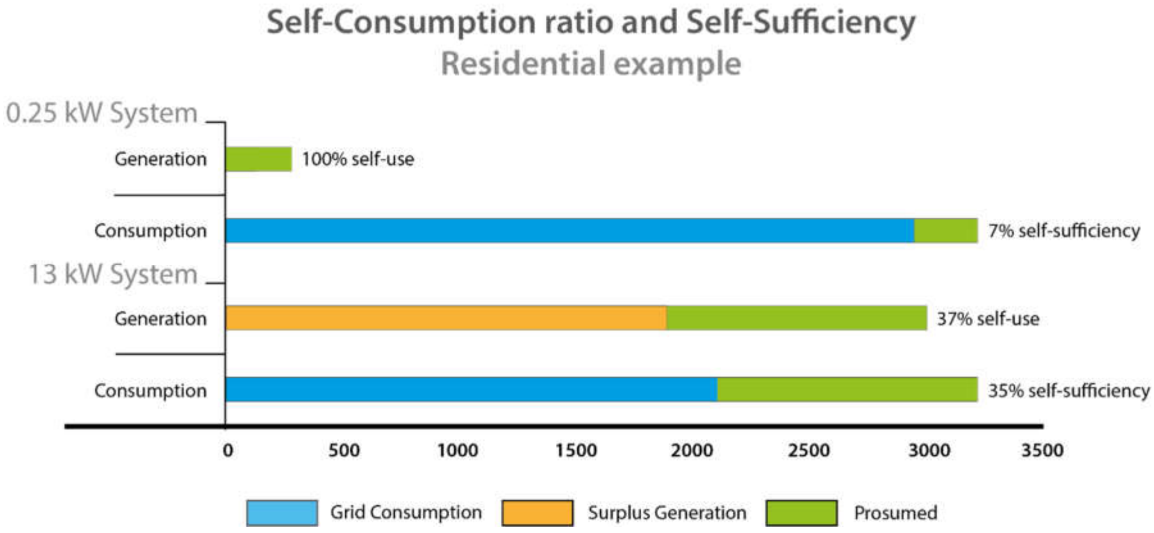


Figure 9 - A practical example of the self-consumption and self-sufficiency ratios, in the residential sector (Source: Adapted from IEA PVPS 2016)

1.1.4.4 Market integration of renewable energy

An electricity market is a system enabling purchases, sales and trades of electricity, generally in the form of financial or obligations. Short term energy purchase bids subject to supply and demand principles to set the price, usually happening on a daily or shorter basis. Long-term contracts are done through power purchase agreements and generally considered private bi-lateral transactions between counterparties.

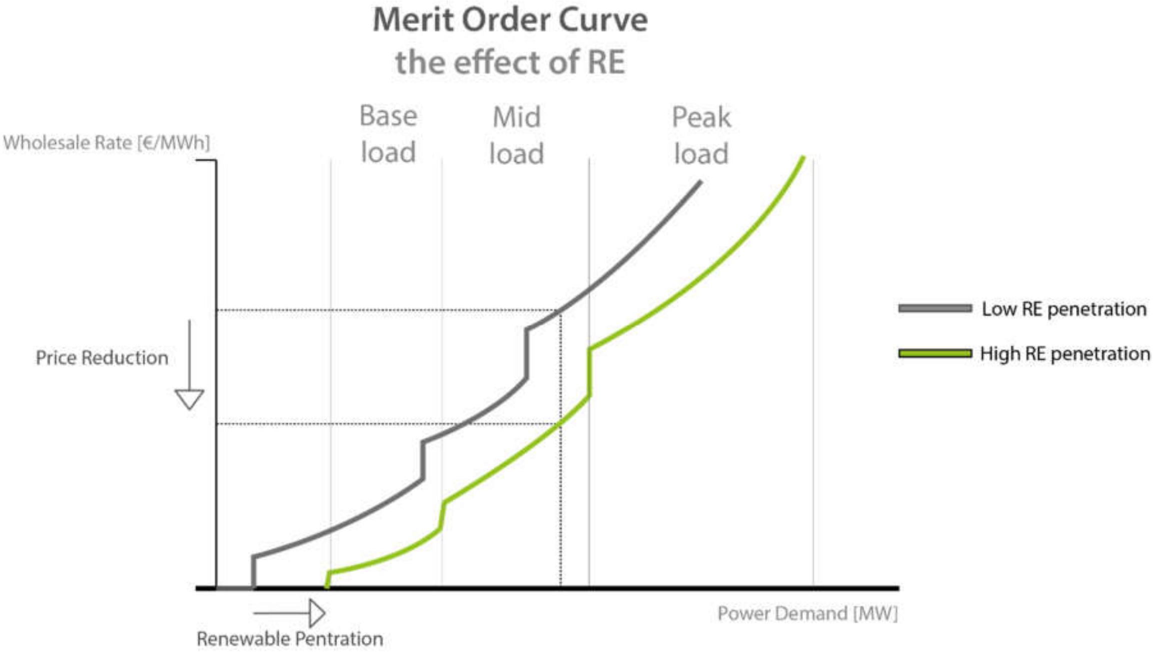
"In a perfectly competitive and transparent market, it is then possible to build the relationship between the electricity demand at a given time and the associated price by sorting energy sources in growing order of marginal cost. This step function is called the merit order curve ("MOC")"[14].

The behavior of non-dispatchable RE is unusual, since it does not act as a base, mid or peak power plant. Guaranteed dispatch policies gives RE production a priority in grid access, i.e. the energy will always be used to supply demand[14]. Any RE production will therefore decrease demand for other power sources. This translates into lower wholesale electricity prices, as can be seen in figure 10, this impact is known as the Merit Order Effect (refer to chapter 4.4.1.2).

Regarding market integration, variable renewabe energy technologies present challenges in adpting to existing market pools, these handicaps can be summarized in two issues:

- **Non dispatchable generation**; the fact that output control is limited for RES such as PV or wind power, and forecasting complex, it is hard to estabelish power purchase contracts for renewable generation, in standard market models. This impedes a predictable or controlable revenue stream;

- **Higher initial investment**; contrary to fossil based generation renewables have a very low marginal cost (OPEX), due to free/abundant resource, but have a high initial investment (CAPEX)., high investments whith uprudictable revenue streams increase investment risk in current market conditions.



-

- *Figure 10 - Figurative merit order curve and the merit order effect of Renewable Energy (Source: Author)*

1.2 Problem definition & motivation

The problem definition and research questions that motivated this work were divided into two groups. The first points out why there is a need for self-consumption policy analysis, and regulatory best practice evaluations. The second looks into emerging "aggregation" models, such as peer-to-peer energy trading and shared generation, their implications and how they can enhance existing policies. To extendedly include the different configurations of these "user aggregation policies", we will refer to them as prosumer aggregations policies throughout the work.

1.2.1 Why self-consumption?

Problem 1: Unclear future for RE public policies and DG generation, with the phasing out of subsidies.

Traditionally, public policies for non-dispatchable RE were designed to support technology diffusion and development, with the hope of achieving technology cost reductions. Indicators tend to show that this was a successful attempt to some extent, however a new dilemma arises of what the future of RE public policies will look like with the phasing out of subsidies.

Self-consumption policies have been praised as a way forward for DG and RES in face of this trend for unsubsidization. Even though in recent year they maintained a degree of incentive, either indirectly through net-energy metering or directly with net-FiT for surplus generation for instance, increasing examples of the decrease of these supports can be seen across the world such as in the US, Europe or Australia. Market-based approaches are often argued instead of governmental interventions.

Problem 2: Both external and internal drivers seem to push for a rise of self-consumption system configurations, but the right to self-consume is not universal.

Increased grid parity of RE, rising electricity costs, unbundling of the energy system, cost reductions and scalability of PV, citizen awareness and spontaneous participation, can all be seen as potential drivers for this transformations in the energy system and the roll-out of policies that grant the right to self-consume or self-generate. However, the majority of countries do not provide any legal provisions for self-consumption.

If the trend for market integration is put to practice traditional full export DG regulations are poorly adapted for small scale generators (i.e. residential and commercial), since energy sale prices in most cases might not be sufficient to guarantee an economic interest in the investment. However self-consumption policies can present an alternative in a context without subsidization[21].

Problem 3: Misleading policy labelling, and lack of formal definitions make policy comparison challenging for self-consumption policy.

Comprehensive work that thoroughly analyses the self-consumption policy concept is seldomly found, partially due to the recent emergence of the policy genre. This creates a challenge in identifying the policy type and preforming compared policy analysis or best practice evaluations. There are usually three criteria that point to the need of concept analysis, that all seem to check in this topic:

- Few or no concept reviews are available in the focal area of interest;
- Concepts available are unclear, outmoded or unhelpful;
- Literatures and researches on a concept do not match.

There are few wide reviews that acknowledge this new policy genre (refer to topic 1.3), with the exception of energy organizations that focus on RE, in the scientific community most work dedicated to techno-economic case studies rather than focused on energy policy and regulation. A degree of experimentalism in such policies often induces policy mislabeling and lack of best practice benchmarks.

Problem 4: For the different energy sector stakeholders, the impacts from mass diffusion of self-consumption systems is still unclear or inconclusive.

Mostly due to the early stages of present policy diffusion the macro scale outcomes are yet to be clear, also the impact of local context and system characteristics can complicate policy comparisons. Even so, efficient policy planning requires addressing policy implications of energy self-consumption from their economic, social, technical, political and environmental aspects. Being in the early stages of policy development provides an opportunity to foresee future challenges, adding pertinence to this study in contributing to the groundwork for the future of the energy sector.

1.2.2 Why prosumer aggregation?

Problem 1: Assuming the scenario of low or no public incentives, market-based approaches might not be sufficient to maintain economic drivers

Even if self-consumption can present advantages to full export policies, in a context where wholesale market integration is taking place, there is still a severe handicap for small scale generators, particularly the residential sector, with load matching between generation and production being an alarming issue. This will lead to a decrease in system sizing to guarantee a positive self-consumption ratio, which implies a lower self-sufficiency ratio, far from net-zero scenarios[1]. Low self-sufficiency ratios additionally lead to low economic relevancy for promoters, which might discourage the investment.

It is often forgotten that alternative ways to value your surplus production can be found, without resorting solely to the energy markets (referring to wholesale energy poll) or the need for public incentives, such as energy trading with other citizens or organizations. Existing models inspired by these approaches also offer different drivers that can be appealing particularly when the economic compensation is low, such as social or environmental drivers.

Problem 2: Particularly for the residential sector, load matching is a challenging issue without additional equipments

Load matching between generation and consumption on the typical household is often low, with self-consumption ratios under 40%[11]. Optimization strategies, such as storage systems or DSM, are still limited. However, if we aggregate residential profiles a smoother load curve can be attained, potentially leading to grid export peak shaving.

Therefore, prosumer aggregation could be an alternative route for optimizing the self-consumption ratio optimization, in the absence of cost-efficient technological solutions, or public incentives.

Problem 3: Potential market is heavily restrained to those with appropriate site and resource conditions

With on-site, behind the meter self-consumption, the potential market is heavily restrained to user's without the appropriate site and resource conditions, typically less than 26%[22] of small buildings have the conditions to install a PV system. Additionally, this standard system configuration presents several challenges for cities and multi-house buildings, constraining a large share of the market from investing. Economies of scale with shared generation systems, can also increase economic payback on these systems, and unblock investment opportunities for lower income households.

---

[1] There is a growing trend for building codes to enforce nearly zero, or net-zero energy consumption for new buildings.

Problem 4: With the liberalization and unbundling of the energy sector, the grid can potentially be seen more as a common asset, accessible to an increased number of agents, ultimately end-users.

The grid is evermore unbundled from monopolistic ownership and use, even so it is still an asset that is mostly accessible for energy retailers. Under proper regulation and supervision from the grid operators, there is no reason why energy transfer through the public grid should be constrained to other agents, possibly through the payment of standard grid charges, or local network charges that offer discounted values proportional to grid usage (also called wheeling charges).

1.3 Literature review

A comprehensive literature review was conducted to assess a body of research that addresses the research questions. The first part looked into the self-consumption policy theme, a combination of key words including, “Energy Policy”; “Policy Analysis”; “Self-Consumption”; “Net-Energy Metering”; were used to screen through different search engines. The literature shows us that there is an increasing amount of publications starting in 2010 for self-consumption. The net-energy metering theme has a wider historical presence, while self-consumption increased its share of publications in more recent years. It is noticeable that the majority of scientific publications and compared analysis on self-consumption are dedicated to techno-economic analysis of the generation systems performance in different typologies of self-consumption policy[21], most of which are location/legislation specific, while researches dedicated to a policy or regulatory analysis of the theme are seldomly found. Nonetheless, more profound researches dedicated to the wider aspect of self-consumption policy have started to be published as of 2014 approximately, most of them were not developed by the academic research community but by energy sector organizations, such as the International Energy Agency’s (EIA) renewable energy technology developments (RETD) program, with the report entitled “RE Prosumers”, or SolarPower Europe (former European PV Industry Association, EPIA)[11], [23].

Initially no publications were found that conducted a wide assessment on existing self-consumption policies and their main regulatory characteristics, that acknowledge all different existing typologies (refer to chapter 2.2.3), the closest examples were study cases that briefly reviewed a few number of countries[20], [24], [25]. However half way through this work (may 2016) IEA’s Photovoltaic Power Systems Programme (PVPS) launched its first report entitled “Review and analysis of Self-Consumption policies”, that scrutinized 20 examples of self-consumption legislations. This work builds upon IEA’s RETD reports abovementioned, moving from prosumers to these particular policies, and constitutes a remarkable contribution for the literature in the area. The work effectively separates different typologies of self-consumption and defines parameters aimed at categorizing all kinds of policies supporting self-consumption and to clarify the wording used in several countries, especially net-metering and net-billing schemes. According to this study a mechanism that allows energy consumption in real-time (or per 15 minutes) is described as a “self-consumption scheme”. An incentive scheme that allows compensating production and consumption during a larger timeframe (up to one year or more) is called “net metering scheme”. In case, where the compensation can be calculated on a cashflow basis, rather than an energy basis, we will refer to it as a “net-billing scheme”. Although useful and groundbreaking, there is a confusion around self-consumption as an action, and self-consumption as a policy genre (a recurrent problem further discussed in chapter 2.1.2) this is why it can appear to collapse with the net-energy metering and net-energy billing definitions presented, as they can be perceive not relatable concepts; it is therefore the author’s opinion that the analysis this work conducted in the terminological aspect of policy labelling does reach the extent needed to fundament it, further work could be useful to clarify and define these policies and their relations.

Three relevant aspects were revealed from existing literature related to the self-consumption policy theme:

- Few definitions of self-consumption policy were identifiable; the few existing references are often repeated[26], [27].
- No review was found that attempts to identify all policy initiatives within the self-consumption policy genre.
- No publication was found that categorically addresses the terminological concept of self-consumption, or the danger of mislabeling surrounding the different terminologies used.

The net-energy metering theme on the other hand, has had extensive coverage of policy reports and research[28]–[30], most of which conducted in the US, but not exclusive to. Here we find policy analysis developed from both scholars, such as Berkeley’s university reports[29]. Or by other organizations such as the National Renewable Energy Laboratory (NREL)[15], [31], the North Carolina Clean Energy Technology Center[32], or the Rocky Mountain Institute (RMI)[13]. An important fact is that the vast majority of publications define NEM as a regulatory arrangement where “the customer is billed by the utility only for the net consumption of electricity during a billing period (e.g., a month)”[33] implying either implicitly or explicitly that there is a retail valuation of surplus generation, at least to the equivalent level of the consumption over a set period. This is relevant since the term has been also used in detriment of Self-Consumption in some publications[1], [28], this raises the problematic of policy mislabeling (as introduced in the problem definition, section 1.2.1), it can further complicate the literature review on the theme for researchers, as it is not clear to what a specific work is referring to.

The literature also evidences a fast evolving scenario for DG generation in the USA, where the majority of states have enacted NEM policies, this is the reason behind the need for North Carolina Clean Energy Technology Center, which organizes the Database of State Incentives for Renewables & Efficiency (DSIRE), to start issuing quarter annual reports on DG policy evolutions, this is a very useful publication entitled **“**A Quarterly Look at America’s Fast-Evolving Distributed Solar Policy and Regulatory Conversation”**.**

To approach a policy theme, it is important to build a holistic view around the problematic, this is why an extensive review of the impacts of self-consumption policy on the energy system was conducted, accounting its different stakeholders, the drivers for this trend and regulatory implications. This search was conducted using key words such as “Distributed Generation”, “Impacts”, “Energy System”, “Grid”, “Energy Markets”, etc. Here a more mature body of work was found that does not necessarily focus on self-consumption policy instruments but the challenges of RE and DG in general. Nonetheless they can help us evaluate the impacts of these policies and discuss them in terms of policy strategy, technical aspects, financial aspects, socio-economical aspects and environmental aspects.

For prosumer aggregation policies, several initial key words where utilized such as “Prosumer”, “Aggregation”, “Shared Generation”, “Community Renewables”. These led to the unveiling of numerous other terminologies that were additionally tested until sufficient body of information had been retrieved, these included “Shared Solar” “Community Solar” “Shared Renewables” “Community Solar Garden”

Most of the search results led us to case specific reviews of local policies and business models, where study cases were retrieved from[34]–[36], these were complemented with interviews to the promoters, and their own commercial information. Wider overviews were found mostly in the USA, due to the variety of schemes available, such as the works of NREL[37] or Institute for Local Self-Reliance[38], although these concepts are found across the globe. Virtual Net Metering and meter aggregation are the most usual terminologies for these regulations, but most examples reviewed were seemingly tied to an NEM context, which fails to provide solutions or alternatives for the whole self-consumption policy genre. Prosumer aggregation policy analysis were hard to find, but the drivers and benefits of such schemes are briefly discussed in many publications. An important contribution to the field was made by University of Technology of Sydney’s Institute for Sustainable Futures, that together with the Australian government renewable energy agency (ARENA), developed a proof-of-concept style research on local energy trading between prosumers, and examining local network charges methodologies (an grid charge model that accounts for the lower usage of the grid in local transfers), this work analyzed the technical, economical but also regulatory aspects of these concepts[39]. A similar experience was conducted in the UK by OFGEM and Open Utility, to pilot test a local energy market model that also predicted energy trading and local network charges[40].

1.4 Objectives

There are two main goals to be achieved throughout the work here developed, the first is to undertake a concept analysis of self-consumption public policies, the second is to provide a proof of concept analysis for prosumer aggregation policies in self-consumption regimes.

To reach these goals we will need to undertake certain steps, that can be seen as subsidiary objectives. To start we will assess existing data, both in literature and on legislation:

- Gather an extensive database of existing policies and regulations on self-consumption, in the international context;
- Determine the common specificities and defining attributes of these frameworks and classify them by typology;

After gathered a comprehensive amount of knowledge around existing frameworks and best practices:

- Review definitions for different genres of self-consumption policy;
- Develop an operational definition proposal that encompasses all self-consumption policy typologies;

- Develop extended definitions for the different self-consumption policy typologies
- Present and discuss key policy and regulatory considerations involved in, or consequence of, self-consumption policies;

The last step is to look into the emerging concept of prosumer aggregation policies, with special regard to those in self-consumption regimes or unsubsidized conditions:

- Gather an extensive database of existing policies and regulations on prosumer aggregation, in the international context;
- Identify the defining attributes of these frameworks and classify them by typology;
- Search for projects and business models that make use of prosumer aggregation;
- Present and discuss key policy and regulatory considerations involved in, or consequence of, prosumer aggregation mechanisms.

1.5 Methodology

1.5.1 Scope

International review

This work will make an international overview of Self-Consumption RE Policy. Historically Europe and North America have been the most active in terms of RE Policies, but in the recent years there has been an undeniable growth of RE diffusion in Asia and developing countries. Knowing the lack of stability of the market and regulations globally, it has been taken in consideration all country initiatives to the author's knowledge. Even though this initial scope is global, further work will be focused only in a certain number of country policies, which represent the main international policy tendencies.

PV technology

Even though self-consumption can be provided from different sources, including also fossil fuels, a correlation can be established between the rise of the prosumer movement and the recent developments on the PV markets, namely in the so called Roof-top PV installations. Thereby this work will limit its scope to PV use in self-consumption. Wind energy, small hydro, biomass or biofuels can also be utilized for renewable energy self-consumption and are actually regulated by many of the policies studied throughout this work, but presently do not show the same maturity for self-consumption deployment in all scales as PV, from small KW installations to MW for more intensive needs.

Grid-connected self-consumption

Self-consumption of renewable energy can happen in two scenarios in terms of interconnection to the grid, as an isolated system that cannot or opts not to be connected to the public grid, or as a grid-connected system, that will interact with the grid by importing and exporting electricity.

Even though both can be regulated by self-consumption policies, this work will focus only on policies that allow for grid-connection, which at the moment present the most potential for deployment and policy diffusion. Also grid-connected policies are more controversial as they interact with a public utility, which will require the adoption of specific regulations.

Market integrated scenarios' perspective

There are several variables in RE policies, some, like the governmental option to incentivize or constrain RE deployment, can induce discrepancies to a compared policy analysis. To avoid such biases, to a possible extent, throughout this work a base scenario assuming a market integrated scenario will be used. This does not represent the author's opinion towards the legitimacy of public subsidies or barriers, those are political options, however a market integrated scenario can be seen as a neutral level in terms of governmental interference, from which decision makers can build upon in direction to their specific goal. Adding incentives to this base case will most likely increase RE diffusion, adding constrains on the other hand can decrease RE diffusion. This disclaimer is relevant as this base scenario will be the starting point for the policy and mechanism analysis.

1.5.2 Work layout

Definitions and Policy Labeling (Chapter 2)

Proposing definitions – Develop simple and inclusive operational definition for self-consumption policies, through a terminology concept analysis. This analysis should be conducted by identifying the defining concepts involved in self-consumption policies, followed by a critique of existing definitions and proposition.

Clarifying self-consumption typologies and their relations - Explore/clarify the relations between the different approaches to self-consumption policies identified in chapter 2. Misconceptions in policy labelling can then be clarified with the help of the operational definition presented in the previous point, followed by a proposition of sub-categories, or typologies, of self-consumption policies can assume.

International Policy Assessment (Chapter 3)

Legislation and regulation overview – Assess existing legal frameworks of self-consumption, in the international context, including net-energy metering variations.

Identify essential policy distinctions – After analyzing different policies developed internationally, this information should be organized by the main differences between the models. This is conducted initially through a table with the preeminent criteria or parameters that differ between legal frameworks. The criteria's will originate different columns (x axis) and nations or states the lines (y axis).

Assessment results – Summarize the information collected in the international survey and discuss the results.

Concept Analysis (Chapter 4)

Conceptual questions – Develop a general analysis of the predictable potential, impacts and tendencies for self-consumption, discussing and presenting considerations to research questions considered imperative for this theme.

SWOT analysis – Summarize the concept analysis with a SWOT analysis

Prosumer Aggregation Policies (Chapter 5)

Prosumer aggregation mechanisms – Research existing legal frameworks that regulate prosumer aggregation or energy share/transfer between prosumers. Classify the mechanisms identified in different typologies according to their models.

Impacts, challenges and benefits – Discuss the predictable impacts of prosumer aggregation models, evaluating the benefits in terms of potential market and investment drivers, and the challenges to implementing such regulations.

Case studies - Review business models and organizations that make use of this kind of mechanisms, presenting case studies for different typologies.

Chapter 2 - Terminological concept analysis

2.1 Definitions

“Self-consumption is the generic term to qualify any kind of situation where a PV installation produces electricity first for local consumption (in the building or nearby or even elsewhere) and injects the excess PV electricity into the grid. All other systems are variants where the treatment of the self-consumed electricity and the excess PV electricity differ.” – Gaeton Masson; founder of the Becquerel institute.

Throughout the literature review it was possible to verify that there are few examples of formal definitions for self-consumption policies and it is often confused with self-consumption as an action. A limited number of publications acknowledge self-consumption as policy genre and examine this specific concept. The lack of consensus around the terminology or definition of a concept, namely a policy genre, can handicap research sharing and experience comparison, and pose a problem in terms of building best practices and identifying policy trends. Concept analysis theory typically states three indicators that point to the need for a terminological concept analysis on a theme, they are:

1. Few or no concepts are available in the focal area of interest
2. Concepts available are unclear, outmoded or unhelpful
3. Literatures and researches on a concept do not match

The first, few or no concept analysis available, was already validated in the literature review and research proposal, no extended concept proposals/analysis were found, a group of works that present a more detailed analysis of the concept was identified, without discussing terminology or labelling issues[18], [20], [25], [41]. The second indicator, concepts are unclear, outmoded or unhelpful is also made evident literature, since the use of different terminologies can make it unclear to the reader what the author is referring to. The most usual terminologies found are self-consumption, net-energy metering and net-energy billing, with boundaries and relationships between them being unclear. The issue of policy labelling, and the often occurrence of policy mislabeling that will be shown throughout this chapter, leads to the occurrence of the third hindrance, a mismatch in literatures on the concepts, for instance net-energy metering reviews very rarely mention self-consumption, the majority of NEM definitions describe it as a model where surplus generation is valued at retail rate, at least as long as it doesn’t surpass your consumption over a prearranged period, but sometimes appears implied for valuations other than retail rate. Most typically such regulations are not classified as NEM, but as NEB. In NEB the economical compensation is dissociated from retail rate, and awarded at lower or higher rates, through billing mechanisms. NEB is also not a consensual terminology; on its own it is not explicit on the export remuneration mechanism or even if it grants the right to self-consume generation. Self-consumption is often referred in these cases as pure self-consumption policies, with no export remuneration mechanisms.

This labelling conundrum should in the author’s opinion be clarified, to facilitate communication in the international community, under the terminology self-consumption policy (further discussed in section 2.2). To that purpose, an operational definition is developed and proposed in this chapter. An operational definition is used to define a concept in terms of how you plan to measure that concept, in the case of a policy genre it means how we can verify if the observed policy falls within that genre.

The goal of this research is to, by providing a more profound analysis on this issue, be used as a reference to the terminology chosen in future researches and reports.

An operational definition can be attained by indicating the critical concepts, or defining concepts. These are the mandatory characteristics to classify as a self-consumption policy, the intrinsic or unique properties that distinguishes them from other policy genres. These properties can then be applied to evaluate if a specific policy falls within the self-consumption policy spectrum.

2.1.1 Critical concepts

The assessment conducted allowed gave us an overview of what characteristics separate different policy approaches, yet now the analysis aims to discover what the policies have in common transversely.

The first critical concept, common to all policies reviewed, is that it grants users the right to partially or totally self-consume their own generation. This is a seemingly natural and straightforward concept that justifies the terminology employed.

The second critical concept is that self-consumption policies allow and regulates grid-interconnection, or grid-tied configurations, this separates them from off-grid self-consumption that is not within the scope of this research, as mentioned in the methodology chapter. This connection does not imply however that there is a monetary compensation in case of energy export by the DG system to the grid.

These two defining concepts are present in all the policies reviewed, and together they separate them from other DG policy typologies such as full export types (i.e. traditional FiT's; FiP's; Tenders) or those for isolated systems.

It is important to acknowledge that the second critical concept presented is not necessarily unique to self-consumption, since it can bear significant resemblances with dispatch priority or guaranteed access to the grid provisions already existent in other DG policy typologies. These concepts assume that if there is DG generation, or surplus generation in the self-consumption case, it has guaranteed access and dispatch to the grid and guaranteed transmission and distribution. Therefore, only when combined can the two critical concepts be used to operationally define the policy genre of grid-connected self-consumption.

A third concept was also considered, although it was not validated as defining concept, nor to be present in all policy initiatives, nonetheless it can be seen as the root for much of the mislabeling taken place, this is the assumption that self-consumption policies have behind-the-meter system configurations. While this is true for the majority of the cases, there could be a regulatory option to have separate meters and the economical compensation might take place through separate cash flows instead of physically through an direct offset of consumption, in the author's opinion these exceptions constitute borderline cases, i.e. they contain some of the critical attributes but it is not clear if they respect all of them, thus requiring further analysis to evaluate within which policy genre they classify. This is the case of most prosumer aggregation policy initiatives that will be examined in the final chapter, such as virtual net-metering, where usually energy offset is made through billing mechanisms, and the production meter might be located off-site. To evaluate if a policy that fails to check this third concept is within the self-consumption policy spectrum, the subsidiary question should be if it respects the first critical concept, or put in other words is the energy value used to offset energy consumption in your energy bill, or is it sold in a purely commercial arrangement, as a producer rather than a prosumer.

These critical concepts can then be used in the following chapters to help evaluate existing definitions.

2.1.2 A critique to present definitions

There is no univocal definition for self-consumption policies internationally, this may be connected to the low level of maturity of this concept. Definitions will vary on their scope, how the mechanism itself functions, the technologies referred to, etc. This ambiguity generates misconceptions on the public's opinion and an additional barrier to compare different policies and their results.

I will start by presenting several definitions proposed by different authors or organizations, and discuss their limitations to help us better understand this issue, with the help of the international assessment previously conducted:

> Solar Power Europe, formerly known as the European Photovoltaic Industry Association (EPIA), in one of their reports defines "Self-consumption as a process by which a single prosumer – residential, commercial or industrial – uses on-site generation to partially or entirely cover its own electricity needs. Solar electricity is in that case used instantaneously, or in a deferred manner if it is stored, below the connection point with the grid"[41].

As we a see, the first critical concept is present, the second is omitted, however there are other assumptions made that did not prove to be present in all legislation during the assessment. Such as the need to use on-site generation or below the connection point, legislations with virtual metering provisions are an example that allows for other system configuration in terms of grid connectivity, furthermore they typically do not restrict self-consumption to a single entity or prosumer relation.

Another common misconception found in other definitions is to bind self-consumption to solar PV technologies, when in fact many of the regulations have provisions for other, or any, technology.

> Self-consumption of renewable energies is defined as "electricity that is produced from RES, not injected to the distribution or transmission grid or instantaneously withdrawn from the grid and consumed by the owner of the power production unit or by associates directly contracted to the producer"[25].

This definition represents another typical misconception, where we define self-consumption not as a policy instrument, but as the act of consuming my self-generated energy. Thereby this definition confuses two concepts which are interconnected, self-consumption policies must allow for energy to be self-consumed in that sense (the first critical concept), but they also regulate other instances such as the export of energy, the requirements for RE systems grid-connection, etc. But it is interesting to see that this definition does not constrain to a single user on-site system scenario, as the energy could by contracted from a producer. The same problem is found in IEA's publication on the theme.

> "We will refer to this mechanism of energy consumption in real-time (or per 15 minutes) as a self-consumption scheme"[18].

While it fails to define self-consumption as a policy, it does constitute a useful operational definition of self-consumption as an action (i.e. the act of self-consuming, related to the self-consumption ratio). The concept above described is also be present in NEM and NEB schemes, just differing on how generation not directly self-consumed (over 15 min) is dealt with.

> "PV self-consumption: The possibility for any kind of electricity consumer to connect a photovoltaic system, with a capacity corresponding to his/her consumption, to his/her own system or to the grid, for his/her own or for on-site consumption and feeding the non-consumed electricity to the grid and receiving value for it"[26].

This definition starts once more by limiting its scope to PV technologies, which is not correct for a broader definition such as the one that is here proposed, even though PV is the most mature technology for this kind of application there will certainly be a participation of other RE and non RE technologies in self-consumption, and they are considered in most regulatory regimes assessed. Also the size of the system to correspond to the installations consumptions is a political option and not mandatory, usually such directives are used to avoid oversizing of systems in cases where export is highly profitable, but in cases where surplus generation remuneration is low or inexistent, it can actually be deceitful, as from the return on investment perspective the system should not be sized to meat overall consumption, but to meat instantaneous or simultaneous consumption (i.e. sizing for high load matching or high self-consumption ratio).

Another problem with this definition is that it states that the exported electricity is worth a value, while as we assessed there exist self-consumption policies that do not attribute any revenue to grid-exported electricity.

> "Self-consumption; Prosumers could continue to purchase power from the grid, but reduce the amount purchased by using PV to supply a portion of their own electricity needs (and potentially get remunerated for any surplus generation that they may inject into the grid)"[11].

Although this definition tries to simplify the concept, it lacks some formality and falls short in the sense that the system could also not purchase power from the grid, and supply not a portion but the total amount of their own electricity needs. It is important not to limit the future of the definition proposed since there is a growing tendency in the research and development of storage solutions, so we could have future systems that affordably produce all the necessary electricity, be it in a grid-connected or off-grid scenario. It also seems to imply a behind the meter configuration in its last sentence. And again this definition limits the technologies scope to PV which is not necessarily correct, even if it is a major tendency in the adoption of self-consumption.

Through this analysis we could see that all present definitions seemingly validate the first critical concept defined in this work. The second critical concept was not denied in any of the present definitions, but it is in certain cases omitted or implicit. The third critical concept, that was not defended to be necessarily correct, but seems to lead to most of the misconceptions identified such as the limiting of system configurations, and number of entities involved. Many of the definitions included additional elements that do not portray the variety existent in the policy genre, and fail to broaden the reach of the definition.

As a disclaimer it is fair to note that the definitions identified were found in works that do not exactly set out to discuss the nomenclature issue, they are present as necessary step to introduce a specific research that regards self-consumption systems. The low number of definitions found is also questionable, so is the fact that they are repeatedly found as reference in other authors' works on the theme. All this reinforces the importance of clarifying concepts and presenting a stronger broader proposition to serve as a reference for future researches.

2.1.3 Towards a univocal definition of self-consumption

To create this formal definition, two basic guidelines were taken into consideration, simplicity and inclusivity. It is believed that a good definition must be simple in its construction to promote its diffusion and easy understanding, while also guaranteeing that all policies that allow for RE to be self-consumed are within the boundaries of the definition developed. These guidelines were put to practice and operationalized by making use of:

1. the critical concepts characterized before, and after analyzing;
2. the different definitions proposed by other authors;
3. the most relevant characteristics observed in the international assessment.

Accounting these points, the following definition is proposed:

> Self-consumption is a regulatory mechanism by which one or more electricity consumer is allowed to generate their own energy to partially or entirely cover their electricity needs. This installation may be connected to the public electricity grid for energy consumption or exporting excessive production.

The proposed definition starts by clarifying the object, which is a regulatory mechanism not an action. It also does not limit policies in regard to specific political or technical options, such as the number of aggregated installations allowed, the management of the produced energy and energy excess, or possibility to have both grid-connected and isolated systems. Also it is important to notice that no mention is made here on how exported energy is, or is not, compensated.

In the following section a proposition will be made on how to further classify different models, using an extended definition, in order to communicate or point out a specific sub-type of self-consumption policy.

2.2 Policy labeling and relations

Due to the novelty of these policies, and relatively low common knowledge about such mechanisms by the wider audience, there are several misconceptions being created or perpetuated in regards to the different frameworks of self-consumption policy. This section will be dedicated to point out and evaluate these typical misconceptions, so that we can better clarify the different policy relations and hierarchies in the next chapter.

This issue does not solely regard self-consumption policy instruments. Policy definitions are increasingly fluid as the competitive environment of RE continues to evolve, the National Renewable Energy Laboratory (NREL, USA) notices this issue in its report on the next generation of RE policies [15], stating "policymakers are increasingly required to innovate in order to reconcile different policy objectives. As a result, "best practice" may be less about adopting policy 'A' or policy 'B', but rather about combining a wide range of policy design elements into a flexible and well-adapted policy framework. In some cases, this may involve abandoning the traditional policy categories altogether, and pushing out in new directions."

Traditionally policy labels have been adapted and evolved throughout their international diffusion, creating several labelling contradictions, for example:

- Traditional FiT policies where implemented to compensate producers for their system full output, however many countries enacted so called FiT policies that only have this compensation for the excessive energy (such as Germany, Australia, Japan, etc…). In many places these new FiTs, or self-consumption with net-FiT as we argue further into the work, even cohabitate with traditional FiT mechanisms;

- Grenada's "Renewable Standard Offer" Policy is referred to as a net-energy billing mechanism, even though it resembles a traditional FiT mechanism where the full generation is exported, on the other hand Italy's "Scambio Sul Posto" is also commonly referred as Net-Billing yet it allows for the direct offset of electricity consumption through on-site self-consumption[15];

- The state of Nevada, Mississippi and Hawaii in the USA, or the islands of Seychelles, have enacted so called net-energy metering laws, which do not assume a 1:1 basis for compensation of surplus generation within the established rollover period as traditional definitions of net-energy metering require. They compensate energy based on the avoided cost for the utility;

- When the rate design for excessive electricity production is different than a 1:1 basis (such as the examples above), the policy is in certain cases appointed as net-energy billing. However, Portugal and Germany for instance present a wholesale market price remuneration or a FiT respectively, and the policies are denominated as self-consumption instead of net-energy billing;

- Premiums (FiP's) are the common terminology for a set fixed price that is paid to RE producers above the price obtained in the wholesale market, yet the UK version of the economic instrument is called contracts for difference.

These inconsistencies are natural due to local regulatory characteristics and experimental nature of many of these policy instruments, the social/cultural aspects of policy diffusion are also considerable for terminology acquisition, for instance in the USA public knowledge has a greater awareness of the term net-energy metering rather than self-consumption policy for historical reasons, therefore even policies that fall outside of its traditional scope end up being categorized as such, while in Europe the term self-consumption seems to occupy a higher share in the public's knowledge due to the benchmarks of some relevant countries such as Germany. This leads to situations where almost identical policies, such as the Portuguese regulation and the law enacted in the state of Nevada[42], having completely different terminologies even though they present similar structures (i.e. market value surplus remuneration).

It is important however for the international community to set some common ground in terms of language to facilitate communication and understanding, that without limiting national regulatory experiences can provide better means for policy comparison and analysis, and this way allow us to make better conclusions out of the results of each framework. It is expected that with time and practice some standardization will come to policy terminology, this chapter aims to contribute to this discussion through the definitions abovementioned and the policy relationships on the following points. Namely by distinguishing what are here argued as typologies within the self-consumption policy genre, such as NEM, NEB, net-FiT, net-FiP, VoS, etc.

2.2.1 Net-energy metering and self-consumption

Net-Energy Metering (NEM) is commonly presented either as the same concept of self-consumption as here proposed[1] or as its main alternative[22]. This mechanism has been around since at least 1983 in the USA, "where consumers connected small scale wind turbines and solar PV to the grid and wanted to use the electricity generated at different time or date then when it was first generated"[43].

Net-energy metering is usually defined as "a simple billing arrangement that ensures consumers who operate PV systems receive one for one credit for any electricity their systems generate in excess of the amount consumed within a billing period." Another definition states NEM as "a physical compensation of your PV production volume over your consumption volume during a set period of time (year/month/day/hour)" while net-energy billing (discussed in the following section) represents an economical compensation of your PV electricity production value over your consumption value during a period of time[23].

The majority of NEM definitions acknowledge the idea that all kWh of PV generation are equally valorized, regardless of being directly consumed or exported to the grid, as long as consumption and generation happen within a set period of time[20], however there are exceptions to this rule. Part of the exception are those who point out that while NEM has commonly been implemented across the

USA to value exported power from customers at full retail rates, the concept of NEM does not equate to compensation at retail rates[13]. We also have examples of NEM regulations were prosumers have to pay dedicated grid charges (demand or capacity based)[32], in this sense net-energy metering can be seen as retail indexation more than 1:1 energy valuation, as these charges will decrease remuneration.

This is a sensitive issue in the terminological aspect, as both self-consumption or NEM could be presented as the paths for labelling these policy initiatives or genre, also there is a noticeable regional influence on the terminology used across borders. Even though there is no consensus reached if NEM is limited to retail price valuations (1:1 valuation of consumed and generated energy flows), the majority of publications wordings seemingly include concepts of either: energy credit, 1:1 export-import relation, or physical compensation, when regarding excess energy exports. It is therefore considered that NEM experience empirically leads us to classifying it as a remuneration matched to retail rates. In fact, NEM is in many cases taking place with single reading bi-directional analogue meter, that rotates “backwards” in case of surplus generation and it is and often the term chosen to point out retail rate export remuneration typologies.

The US’s Database of State Incentives for Renewables & Efficiency tried to clarify this issue with increasing states moving out of retail valuations, generating frequent mislabeling or communication gaps. According to DSIRE's standards it is stated that “Net metering policy allows a customer to offset all of their electricity consumption on a 1:1 parity basis *within* the billing period.”, when referring to the policy adopted by the state of Mississippi[44] it is mentioned that it “does not meet DSIRE's standards for a typical net metering policy, (…) the policy adopted by Mississippi only allows instantaneous generation and use to be credited at retail rate; all of the electricity exports are credited at the utility's avoided cost plus a premium.” And goes further to classify such policies as net-energy billing.

Considering the publications that present NEM as the broader policy genre definition[2], as opposed to self-consumption policy terminology, this work attempts to reason that NEM does not cast a valid alternative for the self-consumption policy genre, due to the abovementioned issues, that could be summarized in two points:

- NEM is heavily tagged to retail rate regulation; educating the international community would be increasingly difficult;
- NEM is connected to NEB as an opposed strategy; by acknowledging alternatives we acknowledge it as a typology of something “greater”.

Acknowledging this, NEM is not an alternative model, as opposed, to self-consumption, but actually a sub-type of self-consumption that remunerates exported energy at full retail price. As we can see it falls perfectly within the definition of self-consumption proposed in this work, as it allows for the self-produced energy to be self-consumed directly at the consumer installation and considers grid-connection. But what about NEB? Could it be used as a wider policy genre terminology due to its flexibility in remuneration formats (even to the extent of including NEM)? The next chapter will look into these issues.

2.2.2 Net-energy billing and self-consumption

There is also no univocal definition of Net-Energy Billing (NEB). Generally, it is presented as an "Economical compensation of your PV electricity production value over your consumption value during a period of time", in contrast with NEM where there is a physical compensation. The physical vs economical relationship is often confusing from the concept perspective. Take for instance a NEM scenario where there is physical rotation of an analogue meter to account energy credits, and another where a digital meter registers consumption and energy credits to be settled through billing arrangements. Should this last case be taken as NEM, or NEB? This physical analogy could also be connected to the energy credits concept (that inducing a 1:1 valuation), where all energy is associated to retail rate, in regimes other than retail valuation it is more a concept of energy sales (inducing a specific valuation for sale rate).

The Italian scheme, Scambio Sul Posto[18], is often referred to as a NEB mechanism and it allows instant self-consumption of the energy generated. Also in the USA for instance, the states of Hawaii, Nevada and California are transitioning from NEM to so called NEB policies[32], that rather than allowing for full one-to-one valuation of all generated energy, any excessive exported energy is credited at the utility avoided cost rate, however, if we look to the Portuguese self-consumption law[2] it has a similar export remuneration structure yet it is always presented as a self-consumption policy.

J. L. Prol, K. W. Steininger from the University of Graz[45]; defines NEB as a mechanism where surplus electricity is valued at a lower price than the price at which it is bought from the grid while self-consumption is used when the surplus electricity is not remunerated at all. But Germany for instance, also presents a model of self-consumption where the export FiT is less than the energy retail value, however it is not referred to as a NEB policy but as a self-consumption policy. Also the need for a lower than retail remuneration in NEB is not consensual.

The latest report by IEA on self-consumption policies[18] seems to go a bit farther into this issue by stating that "While self-consumption assumes an energy netting (kWh produced are locally consumed and reduces the electricity bill naturally), net-billing assumes two different flows of energy that might have different prices associated with. The costs related to these two flows are netted to calculate the reduction for the prosumer electricity bill". Additionally, it is said that the right to self-consume is not compulsory in NEB.

This last definition conflicts directly with the assumptions and the first critical concept proposed in this work for self-consumption policies. While it might simply be the result of the hybrid policy design and fluid labelling, that the sector has been known for. It is recommendable to carefully evaluate so called NEB regimes in order to determine the exact framework, first and foremost to assess if it involves self-consumption or full export of the gross generation. And secondly to identify how the export remuneration is valued, according to the common definitions, it could include regimes such as Value of Solar, net-FiT, net-FiP, market integration, and others.

---

[2] According to DL 153/2014 energy exports of registered Self-Consumption installations are remunerated at average monthly spot market price (wholesale) and afterword's a modifying coefficient is applied (0.9).

Full export NEB is a borderline case from the critical concept's perspective, if the economical compensation is in any way tied to the user consumption pattern, it might be seen as self-consumption, but if the compensation is purely commercial, then it most likely does not fall within the policy genre as here defined.

NEB terminology by itself is inconclusive on the policy genre, therefore in the author's opinion it does not portrait an alternative to self-consumption as overall policy terminology, some NEB terminology disadvantages are:

- The right to self-consume is not compulsory;
- Not clear if it can include NEM, if not than it is a policy typology within a genre;
- Fails identify meter configuration (i.e. bi-directional meter or separate meter without physical self-consumption);
- Fails to specify the export remuneration rate (i.e. if under or above retail rate);

This having been said, we acknowledge the existence of the term but will avoid employing it throughout this work by privileging more specific nomenclatures.

2.2.3 Extended definition for typologies of self-consumption policy

After establishing a common ground for the operational definition of self-consumption and elucidating some common misconceptions (regarding NEM and NEB for instance), there is an evident need to distinguish different approaches to self-consumption policies. From the assessment described in chapter 0, two particular policy characteristics tend to come forward as the most relevant candidates for this distinction, these are the export remuneration mechanisms and grid compensation mechanisms, since they are only the main distinctive regulatory frameworks but can also depict the long-term strategy and political options.

Notwithstanding it is here proposed to do so primarily by privileging how excess export energy is remunerated. The international community has already informally adopted this characterization method since the name of the policy used usually implies a certain remuneration rate (i.e. NEM, NEB and the Australian net-FiT regimes).

Gaëtan Masson also evidences this trend "direct compensation mechanisms are based on the idea that PV electricity can be used first for local consumption and that this electricity should not be bought from utilities. The part of the bill that can be compensated depends on several options that are used differently depending on countries or regions; this receives various names depending on policy options, from self-consumption schemes to net-metering or net-billing schemes" [20].

This work agrees with the view that generally these regimes foresee that self-generated electricity is used primarily to supply consumption needs, and only in cases of an excessive production there is export to the grid, thereby they are all included in the definition abovementioned for self-consumption policies, nonetheless they differ on how excessive generation valued and that constitutes an important policy vicissitude. Thereby, as here defended, to characterize self-consumption policies with the appropriate name of the respective export mechanism is seemingly a natural step.

With this important separation we can distinguish pure self-consumption with no specific policy for exported energy, from self-consumption with net-energy metering, or self-consumption with net-FiT, for example. This is formally proposed in this work by introducing an extended definition to classify these specific forms of self-consumption, through a type of intentional definition, popularized by Aristotle as genus definition [46]. The genus definition takes the following format:

Definiendum = genus + differentia.

- The *definiendum* is the term or concept you are defining (i.e. A specific type of Self-consumption).
- The *genus* is the category or class which the *definiendum* is a part of (i.e. Self-Consumption in a general meaning; as described above in chapter 2.1.3).
- The *differentia* is the characteristic or group of characteristics that set the *definiendum* apart from other members of the *genus* (i.e. Differentiating by how exported electricity is regulated).

With this said, and together with the information retrieved in the assessment, we can organize SC policies into 5 generic categories, seen in Figure 11, all regarding the rate design for the exported energy.

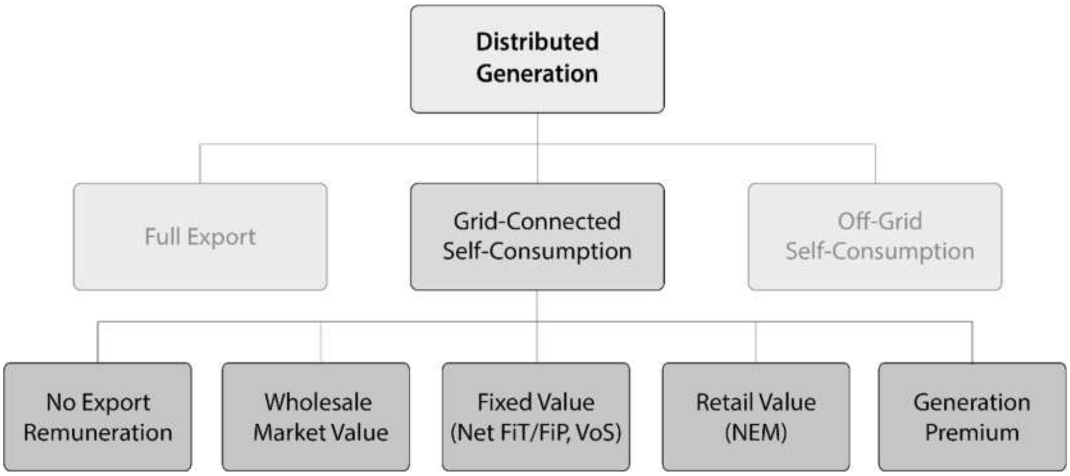


Figure 11 - Typologies of grid-connected Self-Consumption (Source: Author)

From least to the most advantageous policy from a RE promoter perspective in a standard scenario, we have:

- **Self-consumption without export remuneration**; Sometimes referred to as "pure self-consumption". The prosumer does not receive any revenue or compensation for the exported electricity. This is the situation in Spain, or in Portugal for systems with less than 1,5kW.

- **Self-consumption with wholesale market value**; In this model the prosumer exported surplus generation will be indexed to the wholesale market values, or at utility avoided cost. Such is the case of Portugal for systems above 1,5kW where you will receive an equivalent to 90% of the average wholesale market price (OMIE); or the State of Nevada where you will receive the equivalent to the utilities avoided cost.

- **Self-consumption with fixed value**; In this typology a set value is offered to the prosumer's surplus generation exported to the grid. This is similar to what happened with traditional FiTs mechanisms, and this nomenclature was maintained in cases such as Germany or Australia in addition to the SC term. They are here-on-after referred to as "net-FiTs" to indicate that only a positive net value, of generation over production, is considered, to symbolize that only the surplus is remunerated an alternative approach is VoS enacted in Minnesota. This fixed remuneration value or level might also be offered in addition to the wholesale market value such as traditional FiPs, hereon referred to as "net-FiP".

  A particularity of SC with fixed value is that the rate for exported energy can be set at a level higher than the retail price. Such was the case of Germany in the past, which practiced Self-Consumption with a net-FiT, but that now has lowered the rate to beneath retail price.

- **Self-consumption with retail value**; As abovementioned, in this model the excessive energy exported is rated equal to the retail price, meaning that you will be awarded 1:1 energy credits. This policy has been the most diffused of all these five categories, particularly widespread in the USA, but also enacted in several EU and developing countries. It does not exclude the option to apply grid charges or taxes on top of this remuneration.

- **Self-consumption with generation premium**; This model presents considerable differences from all other, as we have a revenue granted to the whole self-generation, be it the self-consumed share or the surplus share. This means that for the self-consumed share of the energy, the prosumer will not only save the equivalent to the retail price in the energy bill, but also be remunerated for every kWh produced. Typically, countries have chosen to create a hybrid between this policy and a net-FiT. Such is the case of the UK, where you receive a generation premium for the self-consumed energy, and an additional export FiT for energy exported to the grid. Germany has also had a generation premium until 2012, when the program was terminated.

These are certainly not the sole possible export mechanisms, and many countries present hybrid regulations adapted from these different Policies. They are however the predominant options observed at the moment.

2.3 Conclusions on definitions and policy labeling

The scientific community is yet to fully embrace this topic with dedicate research and reviews. Most of the work developed around self-consumption regimes identified during this research focuses on comparative analysis and study cases of the economic and technical aspects that often don't provide any new insights beside those of location specific nature. There is an evident lack of work in regards to concept, policy and regulation analysis (with the exception of NEM which is thoroughly examined by several publications in the USA). These researches could be fundamental to the development of best practices and at providing some structural elements to move forward in these early stages of policy diffusion. An evidence of this issue is that the major publications on the theme have been developed mostly by energy sector organizations such as the IEA, and the European solar industry association Solarpower Europe, with a deficit scholar research on the regulatory trend perspective.

There is a real opportunity for international joint fact finding and targeted exchange to discuss the comparative pros and cons of different prosumer policy models and how they are each evolving (or being hybridized) in different jurisdictions. A facilitated dialogue that integrates stakeholders from multiple sectors (e.g. the solar industry and grid operators) as well as from multiple continents could help establish which policies could best be deployed in which circumstances[11].

Final considerations around the terminological concept analysis of self-consumption:

- There is a need to stabilize policy labelling, through the creation of standardized inclusive formal definitions with the international community as concepts develop in maturity. For that reason, an operational definition, and an extended definition, were proposed;

- It was not without though that we chose self-consumption as the policy label in detriment to others, it was considered to be terminologically straightforward to the common reader, and also less likely to induce a bias from empirical notions (i.e. when compared to net-energy metering, even assuming it not to be "retail tagged");

- The is a need to comprehend self-consumption and net-energy metering as the same policy genre, understand what Is the common ground of these policies and its strengths and weaknesses, acknowledge the importance of export remuneration, avoid model competition rather than factual result comparison;

- Net-energy billing on the other hand requires careful analysis as the label could include full export mechanisms that do not relate to self-consumption, constituting a possible borderline case;

- The majority of regulations assume behind-the-meter configurations, although this was not the author's choice, having preferred a neutral definition in this sense. Traditional begin-the-meter models could be seen however as a "standard self-consumption policy" model. And on the other hand, policies that allow for other interconnection configurations could be seen as upgrades to the standard version, or "self-consumption policy 2.0";

- Acknowledging the self-consumption policy genre can enhance experience exchange, policy comparison, clear communication on scientific research, report benchmarks and best practices.

Chapter 3 - International policy assessment

An international survey was conducted in order to identify the current situation of self-consumption policies around the world. This assessment, based on available data, identified 39 countries and 63 states with explicit regulation in this regard and retrieved information in order to characterize the legal frameworks that regulate self-consumption.

As a disclaimer these might not be all the cases of self-consumption regimes, as other might exist that have not been identified by the author. However, they present a variety of policy solutions considered to represent the most relevant trends and typologies of the policy genre. Also they include the most advanced markets in terms of self-consumption diffusion are considered.

3.1 Assessment criteria

To organize the information a preliminary analysis was conducted in order to identify the most relevant typical aspects to retrieve from this research, and unpredictable characteristics we're introduced at the end of the assessment. The following points were considered as the most relevant characteristics:

1. Export remuneration
2. Maximum credit rollover period (when applicable)
3. Grid compensations
4. Aggregate capacity limits
5. Maximum system capacity
6. System restrictions
7. System requirements
8. Technologies allowed
9. Virtual metering schemes (or prosumer aggregation policies)
10. Guarantees of origin
11. Zero bureaucracy models

In this section we will go through each of the policy criteria gathered and briefly explain their main characteristics.

Export remuneration refers to the various regulatory mechanisms that define how excess generation is compensated when injected to the public grid. Excess generation is characteristics examined, justifying the choice of the criteria and brief considerations, together with the summarized results. also known by other terminologies such as instantaneous overgeneration, surplus electricity/generation or energy export. It is important to keep in mind that the exported energy is not the gross RE generation, in self-consumption policies exported energy refers only to the share of energy produced which is not instantaneously self-consumed.

There were five overall typologies of export remuneration, or more precisely export regulation since not all of them consider remuneration. These typologies are:

1. No remuneration
2. Indexed to wholesale market (aka avoided fuel cost)
3. Net feed-in tariffs (net-FiT) or net feed-in premiums (net-FiP)
4. Indexed to retail market (aka net-energy metering)
5. Generation tariff + net-FiT/FiP

Also it is possible to implement hybrid versions of these regulations, or models that include more than one type of remuneration, depending for example on user type or system capacity.

The maximum rollover period is a criteria almost exclusive of net-energy metering schemes, where there are significant differences on the rollover period of the energy credits gained through the energy exports. These periods can have significantly different timeframes, from indefinite rollover to those made on an hourly basis. After this period the energy credits settled. Different arrangements around this settling where assessed, generally it happens in three ways:

1. at retail price;
2. at wholesale price[3];
3. completely lost.

Grid compensations, or taxes directed at prosumers in particular, are another important topic on self-consumption policies. Different types of charges can be enacted, either by a fixed fee (typically annual), or on the other hand based on volume or power (kWh or kW respectively). Also hybrid formats were identified that combine more than one of these methods. Application, registration and inspection fees are also found in regulations, but usually they are not set specifically to mitigate the grid impacts of self-consumption systems.

Also there are different in who is accountable for the payment of these charges, all citizens through government funding, all consumers regardless of using self-consumption mechanisms, or specifically targeted to prosumers. How these charges are set on prosumers through distinct approaches, particularly volumetric charges can vary on what energy should be charged, generally taking five formats:

1. Surcharge the grid-consumed electricity;
2. Charge the self-consumed electricity;
3. Charge the whole consumption, regardless of its origins;
4. Charge the surplus generation;
5. Charge the whole generation, regardless of its end.

An aggregate capacity limit (commonly referred as “caps”) is the maximum allowed level of additional global capacity installed, it is normally set either in a percentage of the grid’s capacity, or simply through an aggregate installed capacity limit, typically set on a yearly basis. Regulators might also choose not to set any limitation on cumulative capacity.

---

[3] Or avoided energy cost.

Another factor is the maximum capacity allowed per self-consumption installation, i.e. how much power you can a single system have. Some countries have chosen to differentiate the allowed maximum capacity according to the type of consumer, be it residential, commercial or industrial.

This criterion can be affected by sizing restrictions (further discussed on the following criteria) that limit the installation capacity in proportion to consumption characteristics.

Restrictions can be enforced through different methods, or in this case self-consumption systems, some already reviewed such as installation maximum power limitation, but not exclusively. Here we present other sorts of restrictions that regulations have put in practice to attain a certain regulatory or strategic objectives. Some for example are created to act as another sizing restriction for systems, additionally or in alternative to other measures, typical restrictions found are:

1. Limiting DG production, or remuneration, to a certain set level, or in proportion to the consumer installation consumption (typically applied in relation to the global annual energy consumption);
2. Limiting the DG installation size to certain proportion with the contracted interconnection capacity of the consumer site.

There are also regulatory requirements that are mandatory for self-consumption systems. Mostly they are related to the technical aspect of the installations, such as the necessary energy meters or inspections for each RES, in most cases a bi-directional meter is required (which can be the existing meter If complying with the regulation). But in certain frameworks an extra meter dedicated solely to the production is also mandatory. Also some requirements were found in terms of the interconnection type, specifying that the system should be connected to the low voltage grid.

What generation technologies are regulated and permitted by law under self-consumption regimes is also a common criterion. Examples where gathered from regulations who only consider solar PV to others that theoretically allow all RE technologies, or even those based on fossil fuels.

Prosumer aggregations policies are another assessment criterion, here we evaluate the existence of virtual metering, aggregate metering, shared generation or off-site generation mechanisms. Nomenclatures can vary widely for these schemes. This information will be useful in the last topic of this work.

On another side we can also hereby identify policies that explicitly deny the existence of such configurations. Such is the case of the Spanish regulation, the royal decree expressly forbids that one installation supplies electricity for several consumers, preventing thus the installations in buildings and hampering the diffusion of the technology in urban areas. [45]

Green certificates schemes, or guarantees of origin, are also found in some self-consumption regimes. Here we verify if the regulation has any considerations towards the attribution of guarantees of origin to the RES, who has their ownership, under what circumstances, etc.

Lastly specific low bureaucracy schemes were examined, to survey if the regulatory framework considers any model through which a self-consumption RES can be installed with none, or close to none, registrations, bureaucracy or inspections.

3.2 Results

The full table can be consulted in digital format, it organizes the main information for each policy into different columns according to the abovementioned typical policy characteristics, whereas each line represents one country/state. These columns identify the main differences identified between the policy approaches undertaken internationally. No other table was found to contain all the information gathered in this research, and including a diverse set of policy models, such as self-consumption or self-consumption with net-energy metering or net-energy billing. Nonetheless a significant number of reviews on individual, or sample groups, of countries where identified [23], [24], [27]. A special acknowledgment should be made to the IEA PVPS report on self-consumption policies released in mid-2016 [18]. In this report an extensive international assessment and policy evaluation was conducted, providing an important contribute to literature around the self-consumption policy theme.

We will now discuss the most relevant results.

3.2.1 Export remuneration results

It is safe to assume that this characteristic of self-consumption regulations is deemed the most important of the regulatory differences in self-consumption policies. One good example of why it is considered the most important distinction is that it has often led to a separation of self-consumption and net-energy metering as opposing policy genres on popular knowledge, when in fact they only differ in how exported energy is dealt with. In chapter 2 of this work we evidenced that self-consumption regulations can be seen as a vaster group of policies, in which we can have different models for export economics, such as net-energy metering. Nonetheless several other export remunerations typologies were surveyed.

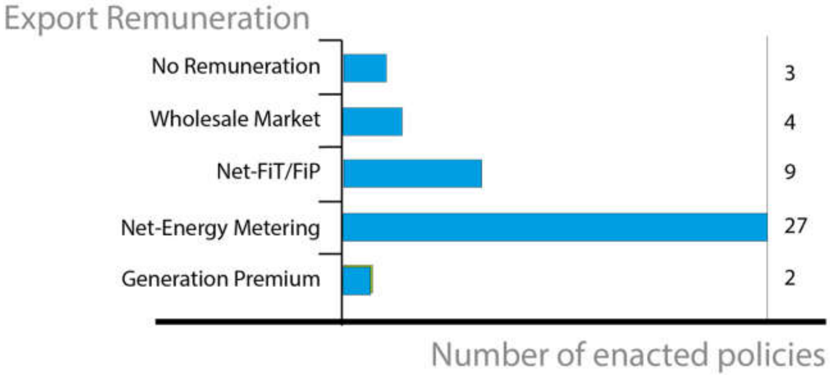


Table 1 - Export Remuneration Summary (countries with several state policies are accounted by the most common typology)

Spain considers two solutions for export remuneration of distributed generation. The Spanish government created two types of regimes, the type 1 has a limitation of 100kW power capacity installed, it is legally considered as a mere consumer and the surplus electricity exported to grid by this type of self-consumer is not remunerated. On the other hand, type 2 can sell the excess electricity must have two legal personalities: consumer, and producer. The producer must become an entrepreneur to be legally able to sell his output as other types of producer. Therefore, in this case PV self-consumption is considered as an economic activity for which they have to tribute like any other entrepreneur (Royal Decree 900/2015).

Some countries, such as South Africa, consider self-consumption on their policy directives, but leave implementation to the province or municipal level, therefore distinct frameworks emerge from Cape Town's net-energy metering program, to provinces that are yet to establish a formal regulation for the activity, and therefore surplus electricity will be not be remunerated officially[4][47].

Portugal has phased out of the micro and mini generation regimes with feed-in-tariffs by enacting a self-consumption regime with wholesale market export remuneration. In this regime excess electricity exported to the grid by self-consumption systems is awarded the average monthly price of the electricity market pool (OMIE) after applying a normalized 0.9 discount on the value. For systems under 1.5kW registration is optional, so users might postpone the right for export remuneration for an easier and less costly registration process, that consist on a mere communication of general characteristic of the self-consumption system to the entitled authorities, through an online portal (Decree Law 153/2014). Also based in wholesale market prices is Switzerland regulatory approached, Switzerland has regulated self-consumption in 2014, and they reward excess generation at the energy cost for the DSO, minus an 8% discount[18].

Italy on the other hand has switched in 2009 from a net-metering mechanism to the so-called "Scambio Sul Posto", often referred to as a net-energy billing mechanism. In the Italian case the energy share exported to the grid is remunerated by two parcels, one named "energy quota", which is based on electricity wholesale market prices and another called "service quota", that depends on the cost of grid services (transport, distribution, metering and other extra charges)[18]. According to the work's terminology this regime is classified as self-consumption with wholesale market remuneration, as the value is indexed to wholesale market prices.

Sweden enacted an export regulation that utilizes a net feed-in premium mechanism. This policy began in 2015, and gives 0.06 €/kWh up to a maximum of 1900 €/year per tax payer. It acts therefore as a feed in bonus on top of the wholesale rate typically offered by utilities. A small number of utilities have offered above market rates for overproduced electricity, but it is uncertain how many will continue under the new FiP bonus, it is also possible for micro-producers (43.5 kWp and smaller) to earn a tax rebate on overproduced electricity[35].

Germany was one of the pioneers of the feed-in tariff mechanism, funded through an electricity surcharge applied to all electricity consumers (EEG surcharge). However, following cost reductions of technology prices the feed-in tariff value has also been reduced to avoid overcompensation of producers. With PV system LCOEs following this drop to values substantially under the retail electricity prices, it has become increasingly interesting to switch to self-consumption models with a net FiT from an economic perspective. In line with this phase-out of subsidized policies in the last amendment to the renewable energy act (EEG) enacted that the majority of new renewable power plants will not receive fixed feed-in tariffs for renewable energy under the EEG 2014. Instead,

---

[4] We mention officially since that might not be the case in consumer installations with analogue meters, some analogue meters rotate backwards when electricity flow inverts, therefore behaving as NEM.

producers of renewable electricity will in principle be obliged to sell directly to the markets. They will obtain support in the form of market premiums paid on top of the wholesale market price for electricity (a FiP or net FiP model), substantially covering the gap to the feed-in tariff amount (with the exception of systems under 100kW). Until 31 December 2016 market premiums will be determined by reference to the feed-in tariff amounts. On an opposite side is France, that has also established a self-consumption regime nonetheless, but gross FiT values and low retail electricity price provide a more attractive environment for traditional FiTs. France has a retail electricity price 25% lower than the EU average[48].

Australia is also an expanding PV market, the different states present their own models for regulating DG, in some cases through conventional gross FiTs (e.g. Tasmania), in other through net FiT in self-consumption, although a significant move towards the second is visible. These net FiTs are a good example of mislabeling in self-consumption policies, since they can present values close to wholesale energy prices (e.g. Victoria 5c$/kWh or South Australia 6,8 c$/kWh), or close to retail energy (e.g. Northern Territory for domestic costumers, <10kW), and even between the aforementioned (e.g. Australian Capital Territory 7,5c$/kWh)[49].

The most common export remuneration policy is net-energy metering, during the assessment we identified 27 countries, at least one in every continent, with this policy mechanism enacted. The USA can be looked upon as a diverse case study since every state has the freedom to develop their own frameworks. As of January 1, 2016, 41 states and the District of Columbia had mandatory NEM rules for certain or all utilities[32], with different characteristics that are shown in the assessment. However, this is a drop from 43 states in late 2015. With the increasing economic appeal prosumers in NEM regimes the issue of export remuneration or the value of solar is evermore discussed, in fact in 2015, at least 24 states formally examined or resolved to examine some element of the value of distributed generation[32]. A shift from NEM can be seen in several states (e.g. Nevada, Hawaii and Mississippi) and others are in the process of developing a successor policy to net metering (e.g. Louisiana and Maine). Typically, the change is made to an export mechanism under retail energy price, often to what is commonly known as “avoided cost”, which indicates a valuation of excess generation based on the utility’s saving in energy or fuel cost. This is somewhat close to what we define in this work as wholesale market value for surplus generation, and can similarly present penalties or bonuses to modify this value. On the other hand, the state of Minnesota developed a value of solar rate that is close to retail value[50].

Finally, we find countries that chose not only to remunerate excess generation, but also to reward prosumers for the energy they self-consume by setting a bonus for each kWh they directly use. At the present time only two countries were identified that still employ this regulation, the Republic of China and the United Kingdom[18], [51]. In both cases there is a generation tariff awarded for every unit of energy produced by the self-consumption system. If there is surplus energy export a net FiT is awarded for the UK, or the wholesale market price in China, both on top of the generation tariff. Theoretically this type of regulations could help unlock markets where due to reasons such as low retail energy costs, or high LCOEs, the energy savings created by self-consumption are not sufficient to make the scheme attractive for citizens and companies. Both these options can seemingly be pointed to national conditions, in the UK it could be connected to low irradiation values that consequently induce a high energy generation cost, close or above electricity rates[19], needing a subsidy to become competitive, in China the policy is most likely attributed to the need to develop its fragile internal market to clear their excess manufacturing capacity. Germany also had a generation premium policy approach until 2012, by then retail electricity prices and an net-FiT were considered enough to drive self-consumption[23].

3.2.1 Grid compensations

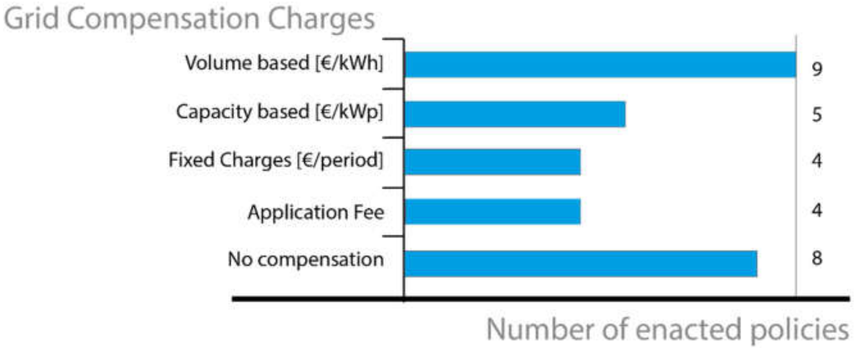


Table 2 - Summary Grid Compensation mechanism for prosumers

Closely linked to export remuneration and not less controversial amongst the different stakeholders involved. In fact, this has been the biggest issue for utilities and grid operators, leading to numerous research works on the impacts and benefits of self-consumption to the public grid, and to the possible effect of underfinancing of the grids costs. This is seemingly critical in NEM scenarios, where there is a loss not only in the self-consumed through the correspondent offset consumption, but also in the net metered exported energy and the later use of these energy credits.

The debate around grid compensations is particularly clear in the USA, where "a growing number of utilities have recently proposed adding demand charges, standby charges, or flat monthly fees on the bills of residential customers with rooftop solar, or putting solar customers into a separate rate class with different rates than other residential customers." This is evidenced by the fact that "in 2015, there were 21 pending or decided utility proposals to add or increase solar charges in 13 states[32].

Europe is no exception to these issues, and even in almost pure self-consumption conditions, such as the Spanish scenario, we can find grid charges on self-consumption systems. In Spain this controversial contribution got famously known as the "Sun Tax". The royal decree in fact establishes a backup charge divided in two parts: on the installed capacity (€/kW) on one hand; and on the electricity self-consumed (€/kWh) on the other hand. This charge applies to both types of self-consumers, but with an exemption to the type 1 installations below 10kW of installed capacity and for the installations located in insular systems[45].

Germany also enacted regulatory changes in response to this issue. Under previous versions of the renewable energy act the power generated by the prosumer was not subject to the EEG surcharge[5]. Repeated surcharge increases (up to 6.24 c€/kWh in 2014) made it more attractive to consume self-

---

[5] The EEG surcharge is paid by regular electricity consumers through a component of their electricity bill.

generated power, without having to pay the surcharge for it. However; as of 1 August 2014, all new self-consumption installations are charged for electricity that is self-consumed, 40% of the respective EEG surcharge for all renewable energy electricity generation systems. Other fossil-fuel based prosumers are required to pay 100 percent of the EEG surcharge. This currently corresponds to around 2,5 c€/kWh, nonetheless, newly installed systems with a capacity of up to 10 kWp and an annual output under 10 MWh will remain completely exempt from the EEG surcharge. This means the residential market segment on rooftops (17% of the market in GW in 2013) is exempt[52].

The Portuguese regulation is also an interesting study case in this perspective, as it does establish grid compensation charges but only after a certain penetration level of RE in the whole generation system. In specific this means a fixed monthly charge based in the aggregated installed capacity that will start when self-consumption systems represent 1% of the overall Portuguese production power, and then aggravated when this value reaches 3%[53].

Similarly the state of Israel NEM regime on the has implemented a back-up charge that will increase with the PV penetration in order to cover such costs [11]. This balancing charge is aggravated with the increase of RE penetration levels, at the moment the charge is approximately $0.04 cents/kWh[54].

3.2.2 Maximum system capacity

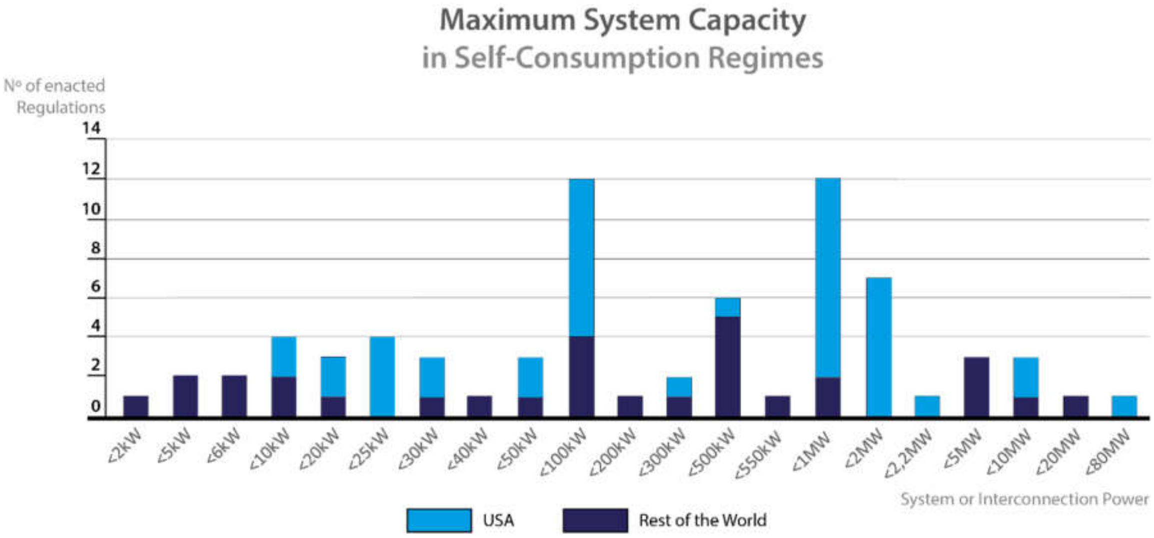


Figure 12 - Installation Maximum Power in Self-Consumption regimes around the globe.

The assessment allows us to see that significant distinctions exist over the maximum permitted system capacity. In terms of scale, we have maximum capacity as low as 2kW in the case of Tunisia NEM, later expanded to 5kW[47], to cases that reach in the scale of 80 MW, such as New Mexico's NEM policy[55].

Figure 12 allows us to see how different regulations have set these sizing restriction to different values. We can also see that there is a more significant occurrence of limitations around the 100kW, 500kW and 1MW, also 2MW for the USA. Where sizing limits are set by sectors, the maximum value for the residential sector was 100kW.

3.2.3 Aggregate capacity limits

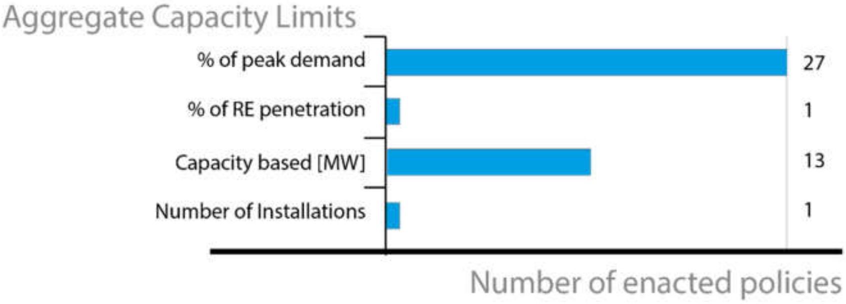


Table 3 - Aggregate capacity limits summary

It is not mandatory to have caps implemented and there are several examples of non-limited policies. Program caps are usually associated with subsidized policies or net-energy metering to avoid unsustainable market growth. But they could also be associated with the maximum penetration levels that can be sustained by the grid for technical reasons, even though some could argue we are still far from reaching those scenarios and this has not been the motivation for present limitations.

Usually aggregate capacity limits are set based on either a maximum aggregate capacity level over a set period, or limited to a certain percentage of a grid factor, such as peak demand or RE penetration.

Limiting to a percentage of peak demand is particularly frequent in the USA, while additional capacity limits are more frequent in Europe, and usually defined on a yearly basis. Tunis is the only example found that had limited diffusion by setting a maximum number of individual self-consumption installations.

3.2.4 Maximum rollover period for NEM credits

This issue is particularly sensitive for utilities and system operators that often express concerns over the seasonal transfer of these energy credits. For instance, if enough energy is exported in the summer time period, when there is a high number of solar hours, a prosumer could potentially use those stored credit to offset an increased percentage of their consumption in winter times, ultimately leading to net zero energy consumers that might represent a burden for utilities and grid financing.

Even though it is often referred that NEM regimes have long rollover periods, this assessment shows us that this affirmation is not necessarily correct, and regulatory options will dictate this period. An interesting example can be seen in Denmark, where regulators have opted for an hourly rollover regime, this approach could potentially ease the worries of the traditional energy agents, while still providing a mechanism to mitigate the effects of variable energy production, and specially the inherit difficulties of matching that production with highly variable loads over short periods.

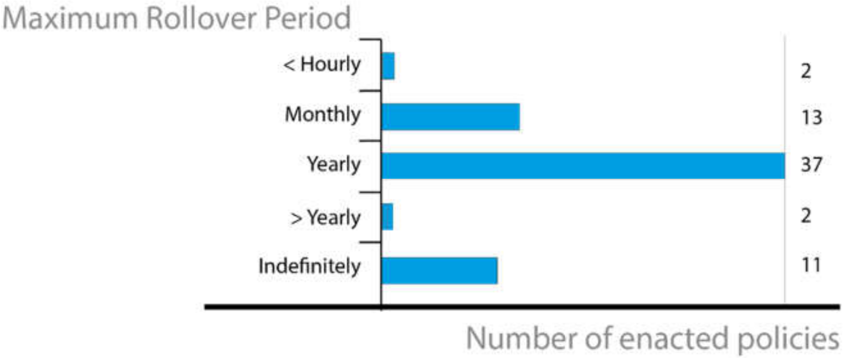


Table 4 - Max rollover period summary

3.3 Conclusions on policy assessment

We were able to identify 39 countries with self-consumption regulations, and 69 statewide regulations. Notwithstanding reports were found that mention the existence of 52 countries with self-consumption legislations[2]. Due to the thorough and time consuming nature of this survey, and the lack of accessible information due to language barriers, the extent of data collection had to be reduced, focusing on retrieving accurate and up to date information on key policy aspects.

The assessment allowed us to confirm that while there are distinct approaches to these regulations, they share common concerns, and the criteria chosen provided a helpful comparison basis. For instance, restrictions, aggregation capacity limits, maximum system capacity or grid compensation mechanism, even though widely different between legislations, all attempt to mitigate or control the impacts of self-consumption through regulation. Policy labelling is typically connected to remuneration export policies, Figure 13 shows us the different self-consumption regimes around the globe according to these export remuneration mechanisms.

Self-consumption with net-energy metering is the most widespread policy at the present moment, providing a simple deployment incentive that can be implemented without additional equipment (other than a bidirectional meter). However, it is not clear that this will remain the long term policy format with decreasing technology costs and revenue erosion effects.

Worries around prosumer impact on grid financing erosion, and cross-subsidy effects, lead to an increasing discussion around the mitigation and containing measures abovementioned, this can make it a fundamental aspect of self-consumption policies, as it can have significant influence on the market attractiveness of such solutions. These issues can also pressure decision makers in terms of export remuneration policies. They also made this survey harder due to fast evolving environment at the present, which might point to the need to maintain a continuous analysis on policy developments.

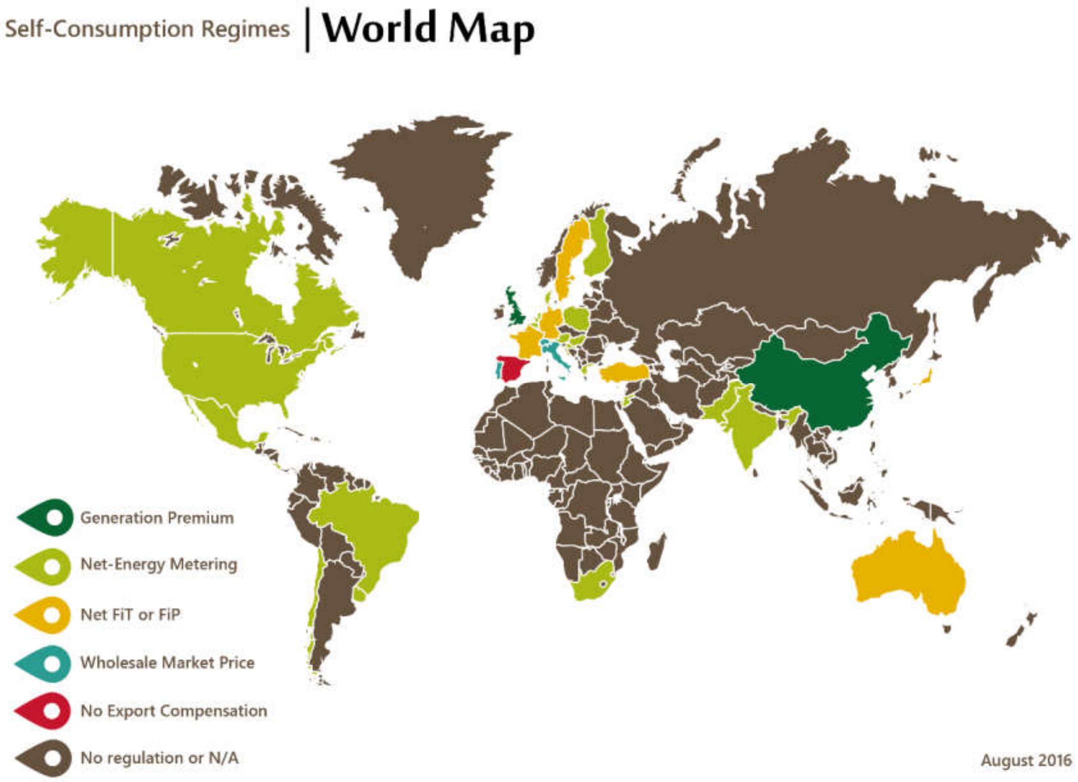


Figure 13 - Self-Consumption Regimes and surplus export mechanisms around the World (Source: Author)

Chapter 4 - Conceptual questions and SWOT analysis

In this chapter we will examine certain conceptual questions implicated by the self-consumption concept, considered relevant or necessary for a more holistic comprehension of the self-consumption theme. We will take a deeper look into the central discussions around the impacts self-consumption, grid-connection and distributed generation. Also to questions such as the motivations for this uprising prosumer movement, the different views towards energy export remuneration or the need for grid compensation mechanisms will be analyzed throughout this chapter.

4.1 Why is self-consumption a growing trend in DG policy?

Why do self-consumption models seem to be gaining market share in distributed renewable generation policies and frameworks? There is certainly not a single answer to this question, but a convergence of factors that lead to the spread of these regulatory frameworks.

In this topic a brief analysis will be conducted of what are the contexts, motivations and drivers that lead to this “new” policy trend.

First off we highlighted the word new, for in fact this is all but a new configuration, on the contrary one could argue that self-consumption is the simplest application of renewable technologies. Most of the first renewable installations where in fact developed for self-consumption, such as off-grid installation for remote or specific applications, with the evolution of technology this niche market[6] has been marginalized. We can verify for example that in the beginning of the millennium off-grid PV had a market share of 20% of installations, while at the moment it holds a share considered irrelevant[5]. Energy poverty and remote electrification programs are another example of common example of self-consumption, particularly in developing countries. However off-grid self-consumption is not the focus of this work.

But even grid-connected self-consumption has an older history than is usually acknowledged, in the USA the first grid-connected policies that regulated and allowed direct self-consumption came up in the 1980’s through the form of net-energy metering policies[43], it is easy to see the advantage of a net-energy metering typology in a context where storage technologies were in a very early stage of development, and RE penetration was far from presenting any sort of danger for utilities, so it was a reasonable approach to ask to inject the excess generation in the grid, and use the equivalent amount in a different timeframe.

However due to the high LCOE of RE electricity self-consumption adoption was more a statement, be it ecological or research and development related, than a viable choice. In fact, it was far more economic to purchase that electricity from the traditional grid than to self-consume. This can point out one of the reasons why the first mass distributed RE policies came up in the 2000’s in a subsidized format and preferred the full output of the energy generation, the rise of feed-in tariffs or similar

---

[6] Considered niche in present conditions, since with a wider accessibility to storage mechanisms grid defection can be considered a bigger threat.

policies. Designed to incentivize technological development, and make investment RES more attractive to civil society.

Until very recently these models remained the number one choice for regulating distributed generation, in 2014 FiTs still maintained a 56,8% share of globally enacted policies, being present in 73 countries. However, this trend seems to be showing some changes, in 2014 Egypt was the only country to adopt this policy format, and most countries show a tendency to decrease the subsidy levels, in some cases with retroactive effects[7][7].

It is commonly accepted that the number one driver for the transition from purely subsidized policies to self-consumption is that the value paid for the exported electricity reached levels below the retail rates of energy suppliers. This decrease on subsidization levels came along with technology cost reductions in recent years, in order to maintain a reasonable return on investment for promoters without over subsidizing. Therefore, it is economically more attractive to directly, or instantly, self-consume that energy, offsetting the need to energy purchase when production and consumption loads match, instead of exporting your full production based on the existing alternative schemes. In simple terms, what we save on the energy bill, is higher than what we would receive for selling that same energy.

The shift to self-consumption policy frameworks and the rise of prosumer status are still in the early stages of diffusion. The lack of specific literature is still an issue (outside the USA-NEM spectrum), however benchmark institutions are beginning to recognize this emerging trend and start to dedicate publications to the theme. The IEA RETD reports "RE Prosumers" develop a comprehensive analysis of the drivers and motivations either for residential prosumers or to commercial prosumers to invest in self-consumption, or using their own words "this IEA-RETD report aims at providing some structural elements to move forward with this challenging yet unique game changing opportunity which prosumer scale-up offers for the energy sector… and for society"[11]. In this report the IEA considers three scenarios under which a prosumer "revolution" could occur (i.e. socket parity, grid-defection, and wholesale competition) and concludes that such scenarios are unlikely to occur in the next few years without an enabling policy framework in place.

As a result, it cannot be said that a non-incentivized mass diffusion of PV is underway in a manner that policy makers can no longer control. However, "the fundamental conditions for such a revolution are moving into place in different countries at an accelerated pace and policy makers have an opportunity to anticipate and react to the potential for prosumer uptake in the near term"[11]. This report also makes an extensive analysis of what could be the variables that constrain or enable Self-Consumption diffusion. They were categorized under economical drivers, behavioral drivers, technological drivers and national conditions.

---

[7] See the Spanish example, where the Royal Decree 900/2015 retroactively changed FiT contracts

4.1.1 Economic drivers

If economic conditions do not favor the return on investment of self-consumption systems, there is a lower chance of user adoption. This makes economic driver a fundamental piece of prosumers' motivation, although other drivers might push for self-consumption.

- **PV system cost**; cost reductions in PV or other generations technology are a positive enabler for prosumers;

- **Retail electricity rates**; both the retail price and the rate design will influence self-consumption. If prices rise, or have a high share of volumetric charges, they constitute a positive driver for self-consumption, on the other hand decreasing retail rates or increasing fixed charges will constrain self-consumption (further discussed in section 4.4.1.1 and 4.5.1). Time-of-use rate design could also motivate self-consumption if there are high rates during sunshine hours;

- **Self-consumption ratio (load matching)**; having a high load matching factor between generation and consumption will increase the economic case for prosumers, and differ part of the risk associated with export remuneration rate volatility;

- **Insolation**; higher insolation values (kWh/m2) will induce higher generation outputs from the same installed capacity, therefore they present a positive driver for prosumers;

- **Export remuneration rate**; the value which is set for surplus generation will play an important roll in system sizing, and the increase the cashflow generated by the system. Higher export remunerations will therefore support self-consumption diffusion (further discussed in section 4.3);

- **Grid compensation charges**; If regulations are adopted to impose dedicated grid charges for prosumers, these can constrain self-consumption (further discussed in section 4.5.1).

4.1.2 Behavior drivers

There are several motivations that can lead consumer to become prosumers, that do not account solely for the return on investment perspective. In fact, there are cases where independence has been more important than economics, and many have chosen to go completely off-grid, with standalone systems, even thought it was not financially advantageous.

Typical user adoption of a new technology, such as a self-consumption system, can be represented by the generic technology adaptation curve, Figure 14, that separates users according to different mind sets and profiles.

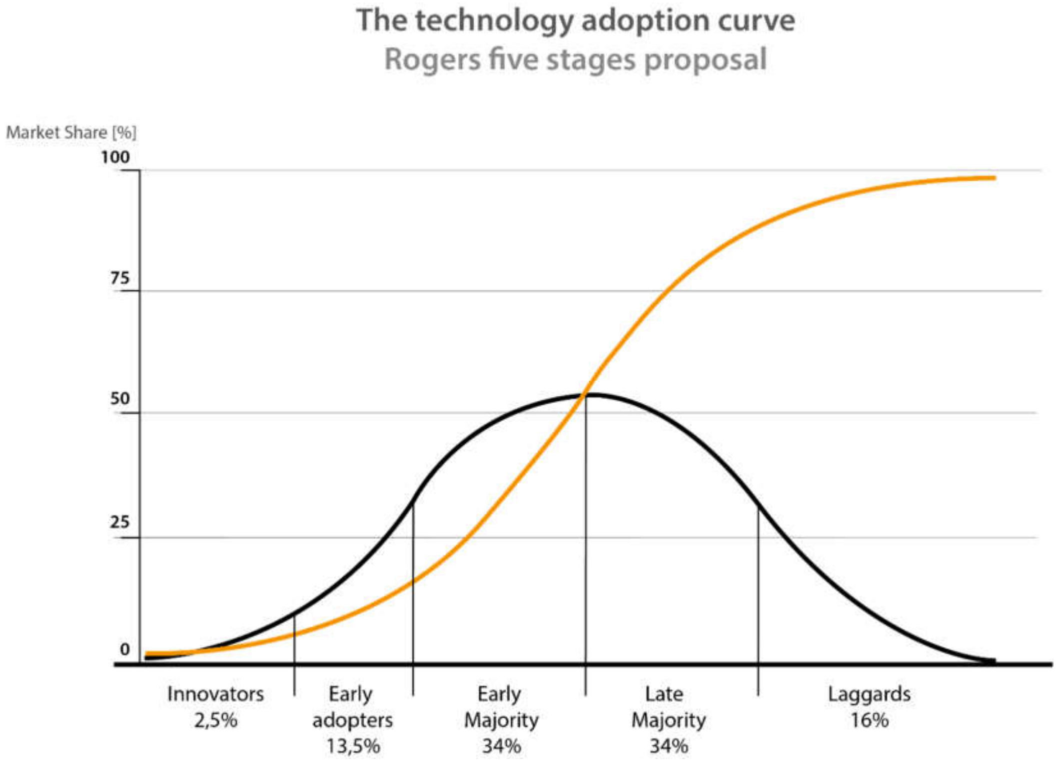


Figure 14 - Rogers five stages of technology adoption (Source: adapted from Rogers 1995)

- **Environmental values**; "Environmental values encompass a range of potential motivations for PV adoption, including the impacts of fossil fuels on air and water pollution, concerns about climate change, a desire to preserve the environment for future generations, and specific environmental disasters"[11];

- **Control and desire of choice**; Some user might be driven by a will to control how there energy is produced and remove the "choice monopoly" from the utility side;

- **Self-sufficiency**; being self-relient and independent from utilities is also a usual motivation;

- **Reliability and safety**; particularly in contexts where grid outages are frequent, reliability and suply safety can be drivers;

- **Status and prestige**; there is a degree of prestige associated with the purchase of innovative or advanced technology, that is percieved by third parties.

4.1.3 Technology drivers

Technology developments and innovations will also portrait fundamental drivers for self-consumption adoption. We are referring to complementary technologies that can enhance self-consumption performance, or even improvements or innovations in generation technology itself.

- **Technology improvements**; either in PV efficiency or in alternative generation technologies that can be used for self-consumption;

- **Batteries**; a reduction on storage system cost can boost the self-consumption ratio, and therefore self-consumption adoption rates;

- **Electric vehicles**; the trend for electric vehicles will increase electricity demand, and potentially mitigate some of the issues associated with variable generation technologies; synergies between RE and eletric vehicles are commonly defended as a positive driver;

- **Energy efficiency regulations**; the increase of the standard efficiency of equipments imposed by regulation can present advantageous and disadvantageos. On one side on-site consumption decrease can make load matching more complicated, bu on theother side smaller generation and storage systems would be required, leading to lower investments;

- **Load management**; improvments on energy management systems will help increase the self-consumption ratio, therefore potentially increasing the economic case of self-consmption;

- **Smart grid infrasctructure**; synergies between grid improvements and DG generation can also be found, "smart grids can encompass a broad range of different concepts, ranging from advanced meter infrastructure, greater communication between utilities and consumer loads, remote control of onsite demand response, etc"[11].

4.1.4 National conditions

National conditions are also a fundamental aspect to describe the prosumer diffusion environment. National policy characteristics, building and housing typologies, the grid infrastructure, can vary widely across borders, and impact significantly the diffusion of prosumers in standard self-consumption policies.

- **Available roof space**; can vary significantly depending on building characterization, "the number of PV prosumers in a given jurisdiction may ultimately be limited by available roof tops. Not all venues have a suitable roof space as a result of roof orientation, shading. Also the local suburban vs urban ratio, multi-house buildings vs single-house, the number of units (e.g. 3 vs. 300), and structure (e.g. high rise vs. low rise) will all affect the available space for system deployment.

- **Share of rental property**; Ownership structure (e.g. owner occupied vs. rental share) is also an important aspect as it is less likely for an investment on a self-consumption system to happen by someone either than the owner, since in case of the need to move, transporting the installation can prove challenging. On the other hand, the owner typically does not pay the rented house electricity bill, therefore self-consumption presents no advantage in terms of in energy savings.

- **Renewable energy targets**; renewable energy policy and targets are dependent of national decision makers, this can lead to the incentive or constrain of renewable energy systems.

- **National energy demand**; if energy demand is decreasing or stagnating in a particular local context, this will increase the pressure of prosumers on the traditional energy supply chain, through an increase of competition.

- **Grid Characteristics**; the characteristics of the local electricity grid will also affect renewables, in places where grid management is costlier, such as islands or remote areas, it is likely that retail electricity rates are also superior, increasing the economic appeal of self-consumption.

4.2 What are the advantages of this transition on DG policy genre?

The first regulations for decentralized RE were oriented towards the bulk export of the produced electricity to the grid. Micro-production schemes, FiTs, Tenders typically subsidized the gross energy production through a RES with a dedicated export meter. With self-consumption there is an implicit transition from the gross export of production to partial export, inversely proportional to the self-consumption ratio. Assuming that self-consumption is grid-connected, and that retail parity, or socket parity, has been reached, self-consumption models with energy export can provide simple overall benefits, such as:

- **Grant citizens the right to self-consume** and regulate grid access. Accepting civil society as a spontaneous contributor towards a more environmentally sustainable energy system;

- **Decrease public subsidizing**, avoiding the portion of RE that is self-consumed. Thereby minimizing the necessary budget for the same additional RE power;

- **No need to establish aggregate capacity limits**, this way we avoid diffusion constrains that are not related to grid limitations (e.g. no economic stability related caps);

- **No additional barriers or costs**, for any of the stakeholders, when compared to full export methods;

- **Allow for a diverse range export policy approaches**, for surplus instantaneous self-generation, this makes it adaptable for both RE favorable or unfavorable governments;

- **The principles of self-consumption have no time limit**, the excess PV electricity remuneration schemes can have a limit in time: feed-in tariffs are limited in time (China, Denmark, France, Germany…). After the 10 or 20 years, the question remains of the remuneration of the excess electricity[18];
- **Provide a strong policy backbone**, to give some much needed regulatory stability to the RE sector.

"Self-consumption remains the way to go: the only business model for PV in the future outside of utility-scale plants selling their electricity is and will remain self-consumption – PV as a way to decentralize electricity production and to reduce electricity bills"[56].

4.3 How to value surplus electricity export in self-consumption?

The policy assessment allows us to see that there are divergent approaches to excess export remuneration. This diversity is motivated by different objectives, such as political, strategical or technical, and induce different results in terms of policy diffusion. However, they share a familiar backbone in terms of the instantaneous self-consumed share of the electricity, that might be the key to guaranteeing viable diffusion even in the absence of subsidies or in the case of political uncertainty.

It is reasonable to assume that when exported energy is rated above wholesale market price, someone along the line will have to pay for this difference. It may be via state subsidizing, the utilities or grid operators' revenues, taxes on prosumers specifically or on all consumers, cross-subsidies and rate design. Additionally, export remuneration significantly impacts economic viability of self-consumption systems, and system sizing. This makes it a very disputable topic amongst a wide range of stakeholders, and therefore one that requires careful political analysis.

We do not wish to present the right model to deal with energy export. This option is guided by a complex environment such as country RE goals, political motivations and technical integration strategies. We would rather point out different perspectives in this issue and what can be defended as a minimum regulatory scenario.

4.3.1 No export remuneration

No remuneration for surplus energy exports is arguably one of the most controversial since excess generation will be granted for free to the grid. However, in cases where there is a need to constrain self-consumption diffusion, for instance in a scenario where RE penetration has reached very high levels, policy makers and regulators might consider this solution as it will represent a negative driver for deployment and necessarily reduce system sizing.

4.3.2 Wholesale market value

Wholesale market valuations, or those based on avoided costs, present little or no additional stress to the energy supply chain, governments or electricity prices, with the exception for the self-consumed share revenue erosion. However, this happens by reducing investment profitability in terms of surplus energy export, since the value will likely be under the system LCOE at present technology costs, moreover in residential installations. Therefore, with current technology prices, this mechanism will constrain promoters to avoid export, by decreasing system sizing and increasing self-consumption ratios through optimization strategies (discussed in chapter 4.5.3).

The trend for market integration is pointed by some authors[15], [21], [57] as a desirable and natural path for distributed generation. These policies tend to move from subsidized technology incentives, designed to boost research and development, to a more independent operation through competitive markets, supposedly more compatible with contemporary technology maturity. With market integration the excess generation valuation will be indexed to wholesale market prices. A similar concept is called avoided cost pricing (in the USA), where the value is indexed to the avoided cost for utilities in energy production.

Nonetheless, for most prosumers market integration means that to export one's excess generation you will actually lead to an economical deficit. Hence with present conditions market integration is a price signal to hinder energy export. It also fails to value the environmental benefits of RE and the externalities that are not accounted by the market or by fossil fuels. Some therefore defend "assigning a value to the clean attributes of solar PV generation that are not currently priced, such as avoided carbon emissions" and that these avoided costs "could offset the costs shifted to customers who use electricity from polluting sources"[31].

Inside the wholesale market price export mechanism, we can identify two different trends, one that awards a bonus on top of wholesale market value (a fixed bonus net-FiP), and another that applies a penalty on the wholesale value.

4.3.3 Retail value (NEM)

This policy approach has been one of the main formats up to date for self-consumption, being present in most states of the USA, several countries in Europe and Worldwide. Considered very advantageous in terms of diffusion due to its implementation simplicity, economically profitable since retail rates are usually above the present FiT rates benchmarks. "The adoption of net metering, or state policies that enable solar energy system owners to receive bill credits for excess energy produced, have been integral to the growth of commercial and residential solar across the nation"[58].

It may also present advantages for the Government in the phasing out of RE subsidies, since the remuneration of the exported energy typically is attributed to utilities or grid operators, without directly stressing national budgets or electricity price, however on the long run it can also lead to rising grid charges in order to maintain the energy systems sustainability. This issue is in fact why it has been arguably one of the most controversial RE policies at the moment.

The term net-energy metering bears a worrisome tone for traditionally utility stakeholders, that tend to point out that it can potentially aggravate two common issues with self-consumption, that might require proper mitigation of their effects (these issues will be further discussed in the chapter 4.4):

- **Revenue erosion for utilities**: Utilities, or certain energy system agents, not only lose revenues and access charges connected the self-consumed part of what they would traditionally sell to a consumer, they must also be prepared to deliver the energy credits equivalent to the energy export, at any given time. With a well dimensioned RE system and with the credit rollover between energy bills the prosumer can actually achieve a zero level of net consumed energy. Representing only a logistical problem for the utilities.

- **Underfinancing of the grid costs**: NEM prosumers receive the full retail price for the excess electricity they export, in which are included the components of the retail tariff that represent taxes and grid access tariffs, meaning they will get 1 kWh for free for every 1 kWh exported. A typical analogy made suggests NEM uses the whole grid as a battery, however NEM doesn't pay grid costs for this service, i.e. the credited energy. This leads to a diminishing of the grid tariff revenue, which should cover the network operation and expansion costs, that might need to be compensated elsewhere.

The contemporaneity of NEM controversy is made particularly clear in the USA, where almost every state is enacting revisions to its NEM policy. "In 2015, regulators, lawmakers, or utilities in at least 46 states studied, proposed, or enacted policy changes pertaining to net metering, valuation of distributed solar, fixed or solar charges, third-party or utility-led rooftop solar ownership, or community solar"[32].

Utilities and consumer groups in regions with growing presence of NEM have begun to express concerns about the potential rate impacts, often referring a utility "death spiral" scenario (i.e. the cycle in which the offset of load by the consumer, via self-generation, leads to less grid-consumption, decreasing supply chain revenue, leading to rate increases, which on its hand incentivizes more self-consumption). In contrast to these utility concerns, some authors have stressed that the "death spiral" concept is exaggerated and could be readily addressed through modest changes in rate structure, or through changes in utility business models[11]. Also NEM advocates defend that DG provides useful grid services, beside the environmental benefits, which should be accounted in a holistic approach to these regulations.

The fact that the North Carolina Clean Energy Technology Center, which organizes the Database of State Incentives for Renewables & Efficiency (DSIRE), has implemented since 2014 a quarterly report on the Solar PV across all States is evidence of the dynamic changes happening in the USA around the PV and NEM theme, and that there is a recognizable need to permanently evaluate policy diffusion, innovation and impacts. The name of the report itself is self-explaining *A Quarterly Look at America's Fast Evolving Distributed Solar Policy and Regulatory Conversation*[32].

From a purely technical perspective it is fair to say that net-energy metering regimes do not reflect the time variations on energy cost, or market value. Therefore, net-energy metering systems fail to provide user the correct signals to support load matching and an opportunity to develop synergies with the grid is lost.

4.3.4 Fixed value

Fixed contracts such as FiTs, fixed level FiPs, Generation tariffs or value of solar approaches are, on the other hand, supported by governments, who typically also transfer this cost to consumers through the enactment of electricity surcharges.

In the recent years the sector has witnessed what seems to be a tendency to decrease export valuation in self-consumption regimes, Germany is an example where export FiT's have gone from above retail rate to under system LCOE in a few years (see Figure 15), pushing distributed producers to self-consumption configurations. These changes to export remuneration are usually encouraged either by cost reductions in technology and adjust investment rate of return.

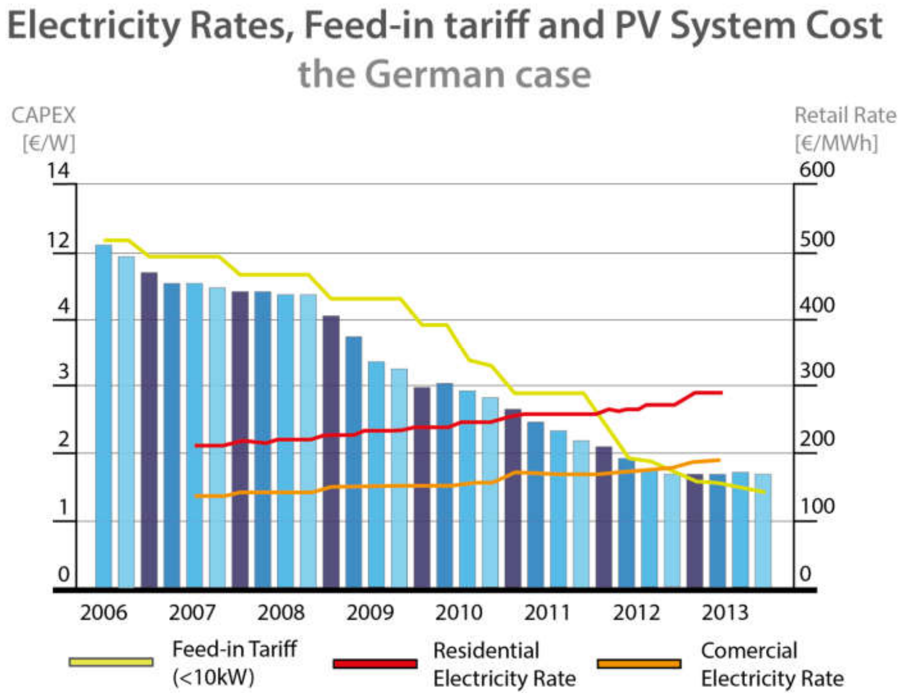


Figure 15 - Development of FiT payments, Retails electricity rates and systems costs in Germany (Source: adapted from Ferroukhi 2014)

In the USA scenario some states moved towards "value of solar" calculations to set the rates at which PV output is purchased, sometimes going above retail electricity rate. The state of Minnesota developed a methodology for setting a rate based on the value of solar, this was used to develop a tariff rate in 2014[50], another value of solar tariff has also been developed by the municipal utility in Austin, Texas for residential PV[59]. Value of solar tariffs are similar to value-based FiTs, such as the one adopted in Portugal previous to the self-consumption regime[11].

4.3.5 Final considerations

The export remuneration mechanism enacted can affect both the prosumer's economic drivers to invest and the energy system's financing due to the cost of these incentives.

Naturally from the prosumer's perspective the higher the surplus generation valuation the more profitable the system is (assuming the same grid charges apply), another important issue for promoters is investment risk:

- **Regulatory transformations can increase investment risk**: the ripple effects of regulatory uncertainty are difficult to measure and could include constraints to the expansion of the solar industry, higher costs of capital, and reduced investment[31].

- **Volatile remuneration rates induce unpredictable revenue streams**: since RE generation cost account mostly to the initial investment (CAPEX), volatility, or unpredictable cash flows, can induce higher risk levels and therefore hinder investments and promoter motivation.

Thus in this sense self-consumption with fixed value remuneration mechanism can present a theoretical advantage, as "prosumers are more likely to adopt PV systems if the system can generate a stable and predictable stream of benefits in the future"[11].

On the other hand, for the energy system's economic sustainability, the valuation of this energy should be responsive to its real market price. In a market environment, investors are guided by the energy demand profile, as it will receive different market values according to the consumption level, they are therefore crucial for investment decisions, particularly for non-dispatchable renewable energies. With fixed charges producers lose this sensitivity to wholesale rates, the higher this displacement from real values, the higher the cost of the subsidies will be. Therefore, these profile differences will become a prosumer externality to be sustained by the system[60].

For the energy system, self-consumption with wholesale market is seemingly the most stable regulatory framework that still provides some level of revenue for surplus generation, however present considerations should not ignore the fact that most distributed scale generation is not yet beyond wholesale parity, especially in residential applications, and therefore market integration might be a step to soon that can hinder prosumer diffusion. For that reason, it is argued that an incentive on top of the market value could be a fair compromise, this incentive should be based on the positive externalities not accounted, such as environmental benefits or MOE, and should be a fixed value added to the wholesale market, originating variable, market responding, revenues, instead of fixed level price that induces no signals.

Figure 16 is intended to illustrate different economics of self-consumption regimes. On the left hand side, we see the economics related to the directly self-consumed share of RE generation, that translate as the retail rate through energy savings, with an additional increment in case a generation premium is set. On the right hand side, we have different remuneration mechanisms for the surplus share of RE generation. Figure 16 also helps us see other aspects of export remuneration models, for instance the offset of grid charges, energy taxes, and energy costs (blue, gray and orange colored shares respectively) will represent revenue erosions for different stakeholders such as the grid operators, tax collectors or energy suppliers. We can see that this is unavoidable in the self-consumed share of RE generation, but subject to political options in terms of surplus export. On the other hand, the color green represents public incentives, which will normally be passed on to electricity consumers through are surcharge on their electricity bill, or can also be charged specifically to prosumers.

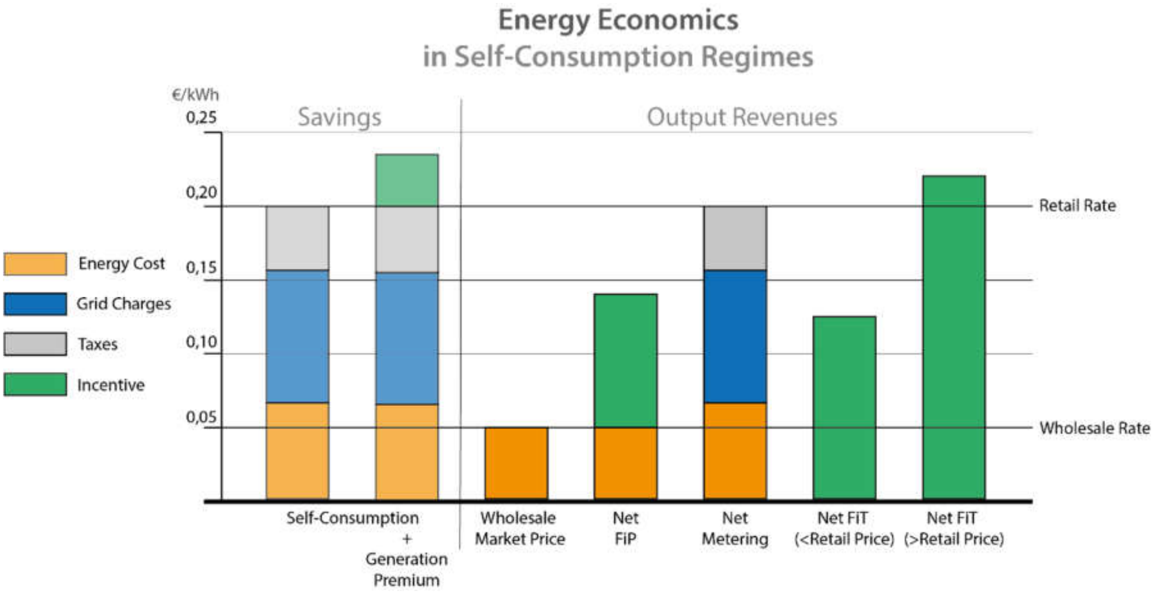


Figure 16 - Economics different remuneration models in Self-Consumption Regimes per Energy Unit [figurative values]; (Source: Author)

We can also see price volatility of different strategies. Assuming that no political or regulatory changes are made, energy cost will be the only volatile component of these economics, being subject to wholesale market price fluctuations[11].

In net-energy metering scenarios, the energy supply chain will be responsible to support the value of the prosumers' energy credits in addition to the revenue erosion associate with direct self-consumption, This might result in pressures to increase grid charges in order to differ some of this support[32], transferring it to consumers or prosumers, if the increased charges are set on all end users it can constitute a cross-subsidy, and be particularly damaging for low income consumers.

The objective of this discussion is not to point out what the best practice would be for remunerating energy export, as for different national contexts, with their vicissitudes and complexities, different mechanisms might be deemed the most appropriate. However, some considerations and strategies should be taken into considerations:

- Self-consumption with wholesale market export remuneration should be the minimum case scenario; this solution can guarantee a minimum level of remuneration for excessive generation. But without added cost for the Governments or energy system.

- Export remuneration, incentivized or not, should respond to markets signals, this can guide investors in line with energy system's needs, and even use them to provide grid services.

- A more supportive transition scenario could be set through the addition of a bonus to a self-consumption with wholesale market remuneration (such as a net-FiT), the combined revenues that PV electricity can command in the electricity markets together with the total value of these benefits, can be higher than the levelized cost of PV. In such cases the value of this bonus ought to be limited to the benefits of DG for the energy system, maintaining a positive or neutral outcome for both the operators and the prosumers;

- Avoid specific charges or taxes on prosumers with market integration, if no incentives are given to prosumers it is arguable that the avoided costs provided by DG could offset the need for grid financing charges (further discussed in section 4.4);

- The market integration should foresee that different agents might wish to manage this integration, and that enabling such participation rather than a sole mechanism (such as the last resort retailer in the Portuguese regulation) might be the key to enable new business opportunities (discussed in chapter 5);

- Stable remuneration levels help guarantee systems economic sustainability and investment payback.

4.4 What are the impacts of self-consumption?

Distributed generation in general, and self-consumption in particular, are usually built as grid interactive models and policies, therefore referred as grid-connected. As was mentioned in previous chapters this interaction will imply disruptive changes to the traditional “top to bottom” electric system that will require careful attention in order to maintain or upgrade the quality of this service provided by the energy system.

The impact of self-consumption in the energy system will not be much different from what distributed generation had set in march, mostly related to the bi-directionality of energy flows, and the fact that they depend on variable and non dispatchable resources.

Firstly, it is important to note that the structure and stakeholders of the energy system can vary among countries or states. Under the traditional model, vertically-integrated electric utilities own and operate all elements of the production and delivery system (i.e., production, transmission, distribution and supply). In contrast, many countries have undertaken some form of restructuring or liberalization of the sector (i.e. EU directives), whereby certain functions have been unbundled and are provided through separate competitive service providers. Even in restructured markets, however, elements of the electricity delivery system (i.e., transmission and distribution networks) typically continue to operate as regulated monopolies under cost-of-service pricing (grid charges)[11], they are often referred to as natural monopolies.

Thereby the traditional term “utility” can be seen as falling out of context, and the different agents are increasingly separated into their different roles, such as the grid operators (divided into transmissions system operator and distribution system operator), energy producers and energy suppliers or retailers. These distinct denominations will be used preferably to remain terminologically neutral. When we refer to utility on the other hand, we are not necessarily talking about a single stakeholder but all possible agents of the energy system.

The impacts of higher levels of renewable energy penetration will therefore be different, and some specific, to certain energy system agents. Also it is noticeable that unbundled energy systems, as in liberalized markets, will face the most challenges in adapting to this new reality, as each agent will have to deal with the impacts undermentioned independently and without the possibility to transfers funds originated in different areas of operation (although not all impacts provoke this effect, notice section 4.4.1.3).

The debate around whether distributed generation induces positive or negative impacts on the energy system has been at the center of the discussion on self-consumption policies rollout, and is one of the most controversial aspects of the new paradigm brought by renewable energies.

“Some electricity industry stakeholders have characterized the rise of prosumers as a needlessly disruptive threat to established business models, to grid reliability and financing, to energy affordability, and to safety. (…) In contrast, other stakeholders have argued that these challenges must be addressed and overcome because prosumers represent a natural, healthy, and necessary evolution of the electricity industry”[11].

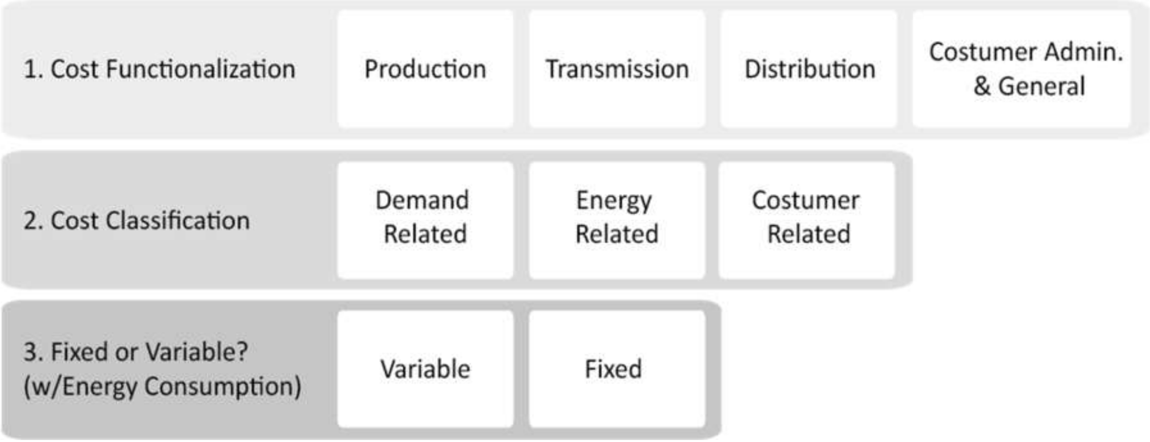


Figure 17 - Utility Cost Classification (Source: Adapted from NARUC 1992)

Figure 17 is meant to give us a broader picture of the typical cost spectrum for the electric system, helping us understand and categorize the nature of certain costs and possible impacts. One important notion to keep in mind is that cost recovery for the diverse system needs is usually made through rate design. And that traditionally these “grid charges” have been heavily associated with volumetric rates (Energy related and variable), which perversely constitutes a strong incentive to energy efficiency and self-consumption. However, when there is a significant percentage of user response to this signal, and energy consumption decreases, there could be a fear of the so called utility “death spiral”, with utility stakeholders stating that the pricing model begins to break down and back-lash[13].

Already we can witness the signs of growing tensions and conflicts among stakeholders in places where distributed resources are more widely deployed, but particularly evident in frameworks where export to the grid is highly valued or subsidized, such as net-energy metering[61],[62],[63]. It is evermore flagrant that existing rate structures and business models, which have evolved over time to meet a complex set of policy, context and economic goals, are poorly adapted to this new environment.

However, the discussion on the value of distributed generation is yet to be conclusive or unanimous in the sector, as these impacts can have both positive and negative aspects, and can't be summarized into a "one answer fits all" model.

This work does not intend to provide an answer to this great question, rather it looks to review and enumerate the most predictable impacts accounted by literature, research and experience.

This chapter will be organized into two groups of aspects: the technical and the financial aspects, both including positive and negative impacts, followed by solutions and strategies to minimize or overcome the related issues.

4.4.1 Financial impacts

4.4.1.1 Revenue erosion

The issue of revenue erosion is one of the most widespread debates around self-consumption, due to its intuitive predictability it is taken by all stakeholders as a certain challenge that will require adaptation if self-consumption penetration continues to develop. "Self-consumption mechanisms are by definition reducing the electricity bill and therefore, under current conditions, the revenues from several actors linked to the electricity system"[18].

Grid operators, energy suppliers and even governments through tax collection, are losing revenues that are correlated with the energy sales to end users. The causality however, could seemingly be related to the number one benefit, or driver, for self-consumption prosumers, which is energy savings (derived from less energy purchased from the grid).

This symptom is aggravated by a stagnation of consumption patterns in developed countries. "The rise of distributed generation would not be as noticeable if the underlying demand for electricity was growing at historical rates"[64].

Energy suppliers face a reality check, having to readapt their business models to a world without continuously growing energy demand, or even with a decreasing demand.

Similarly, grid operators, whose funding of the grid infrastructure and operation is also associated with energy transfers, could pose some concerns of grid underfinancing.

The core of this problem is due to ratemaking methodologies. Grid financing and ratemaking is typically set through volumetric tariffs and fixed charges on grid users to provide sufficient income to cover for the energy system's cost, be it expansion, operational or financial costs. Since traditionally these charges are heavily associated with energy demand, through a tariff on kWh consumed (volume), there is a paradoxical risk associated with self-consumption, as with energy efficiency.

Self-consumption with net-energy metering can be seen as the most aggressive policy in terms of impact to grid funding. Since on top of the self-consumed energy that offsets the need for payments of any grid taxes, there is an additional loss of revenue by the energy credits accumulated through excess generation export, that ultimately could lead to a net zero energy consumer that only pays fixed charges. This use of the grid as a battery, a usual metaphor used to explain net-energy metering mechanisms, does not include in most cases any compensation for the access to that service.

While supplier's revenue erosion can in some cases be argued as a private business problem, when we refer to grid underfinancing the importance of this issue is acknowledged by all sides of the discussion as a public issue. Considering this downturn on the variable income for the grid can undermine the whole economic sustainability of the system.

Assuming that the rise of energy efficiency and self-consumption policies will not be constrained, grid ratemaking will need to adapt this new reality. This has led many to raise concerns about cost-shifting or cross subsidies, cost-shifting can be understood as an increase in general prices of energy and grid access paid by regular consumers, due to the activity of prosumers or specific agents[62].

Many therefore advocate that the refunding of these lost grid charges should be accounted on prosumers specifically, through a dedicated surcharge. Defenders of this thesis often refer that low-income consumers, who do not have the means to adopt self-consumption systems shouldn't have to pay a higher electricity bill[65].

On the other hand, there are those who recall that prosumers are not the sole causers of grid underfinancing:

- **Energy efficiency could provoke similar effects to self-consumption** in terms of revenue erosion, but it seems to be perceived as more financially accessible than distributed generation, not evoking the same reaction in defense of low-income households. Nonetheless this perception is not exactly precise, and the argument can see its basis further weakened with efficiency standards rised and technology costs reduced.

- **Vacation/Secondary housing** for instance also present very long periods of low consumption but still require availability of their contracted electricity power.

- **Subsidized electricity rates to strategic manufacturing industries** (e.g. metallurgy and automobile industries) which other ratepayer classes must absorb through higher rates. "Such industrial cost shifting can significantly outweigh the magnitude of cost shifting attributable to residential prosumers"[11].

Finally, there are those who contend that prosumers provide useful services to the grid, and additional socio-economic and environmental benefits, and therefore they shouldn't be accounted for refunding the entire of revenue loss. This leads us to a following question regarding the need for grid compensation, what are the technical impacts and benefits of grid-connected self-consumption?

4.4.1.2 Electricity markets – The Merit of Order Effect

Variable RE production technologies are usually granted a dispatch priority over conventional sources. This will on the other hand reduce the volume of the remaining electricity demand, so by injecting excess generation to the grid, prosumers, indirectly impact the prices on the wholesale markets by increasing energy supply. This results in a transformation of the overall demand charge diagram that is usually mentioned as the "duck curve", that will be further detailed in the chapter 4.4.2.3. Since this induces transformation on the wholesale prices during the day in form of a curve with a low mid-day price and a high evening price, inversely proportional to the solar generation curve. The extent of the impact would seemingly be dependent on the penetration levels, also correlated with export remuneration mechanisms. This is constrained by restrictions such as the ones assessed in chapter 3, that limit the sizing in self-consumption systems in order to decrease surplus generation, or by maximum system and aggregated limitations. "In all cases, PV is expected to reduce market prices at the time it is injected. The main impact lies therefore on conventional electricity producers that experience a lower market price due to a combined decrease of demand and lower prices"[18].

The financial effect on wholesale market prices is specifically called the merit order effect (MOE). The MOE is described as "the downward pressure on prices exercised by RE sources when they feed electricity into the grid"[14]. The MOE represents therefore the monetary gain induced by PV production over a period of time, if we normalize this value by the total equivalent PV production it provides an order of magnitude of a bonus price that can remunerate the PV asset operators on top of the wholesale price. Such quantity is thereafter defined as the merit-order price (the "MOP").

$$MOE = \sum(\mathrm{P}\_no\ pv{,}simulated - \mathrm{P}\_pv{,}observed\ ) * c\_observed$$

$$MOP = MOE/Total\ PV\ production$$

The result of a study of MOE impact in European countries concluded that the MOP value is close to 100 €/MWh, equivalently, the average market price would have been 3% higher (1.5 €/MWh) had there been no PV generation between 2007 and 2013. Although, as abovementioned, a first interpretation could be that the MOE is less efficient as the PV penetration rate increases, the study's results indicate that the MOP did not depend much on the penetration rate of PV in the country's energy mix, but rather varies significantly with the electricity demand profile, or to be precise, with the correlation between demand and PV production during the year[14].

The authors of the study argue that if the MOP were to be paid to PV plants as a bonus on top of the market price for every MWh of PV produced, the total tariff received would be close to 150 €/MWh, as the average wholesale average price is close to 50 €/MWh, which is in the range of the current feed-in-tariff offered in EU countries.

Lion Hirth argues that if the MOE increases, the larger the price drop will be in the market price. This implies that the market value of variable renewable generation also falls with higher penetration [60].

When regarding these effects, it is often disregarded that if we do have a negative impact on producers who compete with PV at high radiation periods, this will on the other hand lead to a positive opportunity for retailers, which with low wholesale market prices have a greater space for an increased margin on electricity sales. This assuming that there is no time-of-use tariff that mitigates this effect.

Similarly, this could also bring benefits to consumers, since afternoon prices are traditionally high, this assuming that the energy cost reductions are not internalized as additional margin for energy retailers.

4.4.1.3 Investment Risk

"Capital investment in electric system infrastructure is driven in many instances by load growth (or replacement)." [11] This behavior can lead to a backlash when load stagnates or even decreases. In fact load growth stagnation is a trend we are witnessing in developed countries. This stagnation can arise from several variables, such as economic crisis, energy efficiency, the dissociation of energy growth and economic growth (for instance GDP), and of course the offset of grid consumption through self-consumed energy.

This growth uncertainty together with the increase of RE penetration, which usually is accompanied by a priority access to the grid, can significantly reduce the security of the typically long term, large capital investments on new production facilities while undermining the ability to conduct long-term planning and forecasting.

This issue extends also to the transmission and distribution operators, "given rapid distributed generation project timelines and unpredictable technology adoption trends. The rise of PV prosumers, combined with the adoption of new technologies like electric vehicles, has made it much more difficult to predict distribution system needs"[11].

By dampening load growth, prosumers may therefore reduce the opportunities for new investments in electric infrastructure by incumbents and present challenges on traditional utility models in a sector accustomed to 30-40 year planning horizons.

On the other side, it is evidenced that the nature of distributed resources in combination with small scale systems and short deployment times can in fact have reduced financial risk when compared to larger scale investments and therefore could allow utilities reduce their risk or investment by building capacity in renewable energy increments more closely matched to changing customer demand[13].

In this case the impacts are potentially most significant for regulated entities, such as vertically integrated utilities and regulated transmission or distribution service providers. Since the earnings for these agents were traditionally granted by deploying capital and receiving a regulated rate-of-return on those investments. At the distribution system level, that deferral value is often highly idiosyncratic, depending on the conditions of an individual distribution circuit, and current distribution system planning practices in this area are evolving. At the bulk power level, reduced load growth may delay the need for conventional generation and/or transmission network upgrades required for local reliability and resource adequacy[11].

On this case these earnings impacts are potentially most significant for regulated entities (i.e. vertically integrated utilities and regulated transmission or distribution service providers) where earnings are generated primarily by deploying capital and receiving a regulated rate-of-return on those investments.

4.4.2 Technical impacts

We saw earlier that the financial impacts of self-consumption, like revenue erosion, could be similarly pointed at other trends, such as energy efficiency. While this is not an erroneous comparison for financial impacts, in terms of technical and operational interaction self-consumption is considerably more challenging. Energy efficiency will decrease demand at a consumption point, self-consumption will not only decrease consumption, but generate and output production leading to intermittent bi-directional energy flows.

This topic is dedicated to the potential impacts that higher penetration levels of distributed generation can inflict on the transport and distribution grids.

This is a complex question, and has been focus of discussion and research initiatives throughout the globe. While we can certainly say there are both positive and negative impacts arriving from self-consumption and distributed generation, the net value of these impacts is all but a consensual answer and is often dependent on local conditions. The research here developed does not intend to reach a conclusion on this question, as it falls outside the scope of the work, but simply to enumerate the most relevant considerations stated by literature and stakeholders to provide better contextualization.

Renewable advocates tend to say that distributed generation can actually present benefits for the grid that low-cost but large-scale power plants cannot. It is claimed to reduce the need for energy transfer throughout the transport and distribution grids, thereby reducing associated losses, line congestion and required capacity.

On the other side it is stated that distributed generation might impose further grid upgrades to deal with the bi-directional energy flow and variable resource.

4.4.2.1 Technical benefits

- **Avoided system losses**; by generating power onsite, or close to the consumption point, distributed generation avoids the energy that is lost via the long distances of the transmission and distribution system. Most countries in North America and Europe experience transmission and distribution losses of 4-8%[11].

- **Deferred or avoided distribution and transmission capacity**; generating power onsite can also avoid or delay the need for investments in transmission and distribution capacity by relieving upstream constraints or avoiding the need for system expansion. Distributed generation thereby serve as an alternative to transmission system expansion.

- **Resilience**, prosumers who own PV systems with storage could configure their systems to provide back-up power in the event of grid disruptions. Nonetheless current operating standards require that, for safety reasons, grid-connected solar PV systems automatically disconnect from the grid during a power outage (so called islanding mechanisms)[66]. Consequently there is space for technological development to make the most out of this potential resilience.

4.4.2.2 Technical challenges

High penetrations of distributed generation can impose some challenges and upgrades to the grid, or even face some technical limitations. The discussion is also not consensual regarding the extent and relevance of these challenges, or even the penetration levels at which renewable generation can pose a serious issue. Some of the highlighted negative aspects are:

- **Congestion issues caused by excess power export on certain nodes in the system**; the growth of solar PV in certain areas has led to congestion on certain feeders, which results when there is insufficient grid capacity to wheel power. Congestion can occur both at the transmission and the distribution levels, and is a driver of network investments for distribution and transport network operators. Oppositely distributed generation can also reduce congestion in certain cases, specifically on the transmission network. Therefore, this impact needs to be evaluated on a case by case basis.

- **Over-voltage conditions**; Electricity output from distributed solar systems increases the voltage in the network at the point of interconnection. As PV output fluctuates over the course of the day, this causes voltage fluctuations in the distribution lines that deliver power to homes and businesses (Noone et al., 2013). This presents dangers of raising the voltage level above the recommended operating limit. Frequent voltage swings caused by distributed solar can also increase wear-and-tear, leading to higher maintenance costs and earlier replacement of certain components. Utilities and distribution network operator can use a range of solutions to address these issues, including load tap changers in the substation, as well as line regulators and capacitors to deal with these challenges.

- **Back-feeding into the circuit and two-way power flows**; when distributed generation output on distribution lines exceeds the instantaneous load (i.e. demand) on that feeder, it can cause power to back-flow between the low-voltage and medium-voltage lines, or in certain cases, between the medium and the high-voltage lines. In many cases, due to cost reasons, power distribution systems were only designed to allow power to flow in one direction.

- **Stability issues related to inverter tripping because of grid voltage or frequency fluctuations**; this can occur, for instance, when a fast-moving cloud passes over a solar array. The sudden change in voltage can trip the inverters, causing the temporary islanding of the PV system. Inverters are designed to trip at specified voltage levels, partly in order to isolate the generator quickly, and to limit the risks of unplanned islanding. Tripping the PV system offline, however, results in a loss of supply to the network, which can worsen the instability in the network. There can be a cascading effect at low voltage level in areas with high residential PV concentration due to simultaneous tripping of inverters.

- **Transmission operator challenges in forecasting net loads and ensuring appropriate available capacity**; the rise of distributed solar PV in recent years has reduced the load that needs to be supplied in distribution grids. Forecasting these fluctuations in net load, and in the concomitant supply requirements from elsewhere in the transmission and distribution system, has proved challenging.

4.4.2.3 Ramping and back-up power

Since RE technologies, such as wind and PV, derive from a variable source of electricity, in order to continuously supply the system's load at all time additional quickly dispatchable sources of electricity will be necessary, to serve as a backup to variable resources.

"Fundamentally this issue is no different from the problem utilities have addressed for over a century: adapting the supply of energy to match changing consumer demand. The difference is that daily and seasonal usage patterns and the resources that have historically served that pattern have evolved gradually over the last 125 years, while the renewable energy revolution is creating new challenges in a much shorter period of time" [67].

The famous "Duck Curve" is particularly influenced by solar PV generation, but can be further aggravated if there is a timeline coincidence with high levels of wind generation.

As can be observed in Figure 18, for California [68], with higher levels of RE penetration this effect usually provokes a morning ramping down alongside with the sunrise, and an afternoon ramping up accompanying the sunset. This late afternoon ramp is particularly complicated since it tends to jump directly to the evening peak, creating a huge demand difference in few hours.

Besides the economic impact this net-decrease of demand will incite on the energy market prices (as referred in the previous topic *Electricity market*) this will also lead to technical issues regarding the following problems:

- **Short, steep ramps,** requiring to bring on or shut down generation resources to meat an increasing or decreasing electricity demand respectively, over a short period of time[68];
- **Oversupply risk**, when more electricity is supplied than is needed to satisfy real-time electricity demand[68];
- **Decreased frequency response**, when fewer resources are operating and available to automatically adjust electricity production to maintain grid reliability[68];

This will require fexible resources to ensure that supply and demand are at a constant match, so controlable resources will need the flexibility to change ouput levelsand start or stop as dictated by real time conditions.

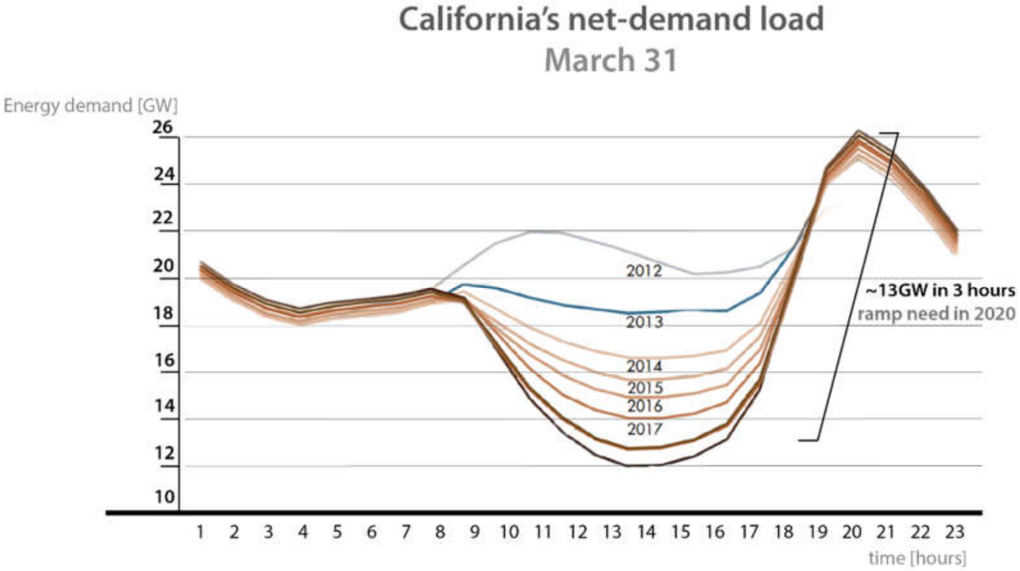


Figure 18 - The "Duck Curve" Effect on California's Load Curve (Source: CAISO 2014)

This issue relates therefore not only from renewable energy, but also to the conditions of the remaining production system and backup solutions, more specifically in terms of response time to ramping needs. Germany, for instance, is already facing this sort of issues, in May 8th 2016, the energy market performed at negative values from 7AM to 5 PM[69], reaching a minimum of -130€/MWh at 1PM, this happened due to a coincident peak of wind, solar and hydro production that led these sources to supply 54.6GW of the 68.4GW of power being consumed across the country at that time, roughly 80%. However, this only provoked an oversupply since nuclear and coal plants already operating cannot be instantly turned off.

Trying to address these challenges Jim Lazar from the regulatory assistance project developed a research called "Teaching the Duck to Fly", where he presents ten solutions, using present technology, to mitigate the issues associated with the duck curve.

Note that not every strategy will be applicable to every region or utility around the world, and every region may have additional strategies that are not among these ten.

The strategies pointed by Lazar are:

Strategy 1: Target energy efficiency to the hours when load ramps up sharply;

Strategy 2: Orient fixed-axis solar panels to the west;

Strategy 3: Substitute solar thermal with a few hours storage in place of some projected solar PV generation;

Strategy 4: Implement service standards allowing the grid operator to manage electric water heating loads to shave peaks and optimize utilization of available resources;

Strategy 5: Require new large air conditioners to include two hours of thermal storage capacity under grid operator control;

Strategy 6: Retire inflexible generating plants with high off-peak must-run requirements;

Strategy 7: Concentrate utility demand charges into the “ramping hours” to enable price induced changes in load;

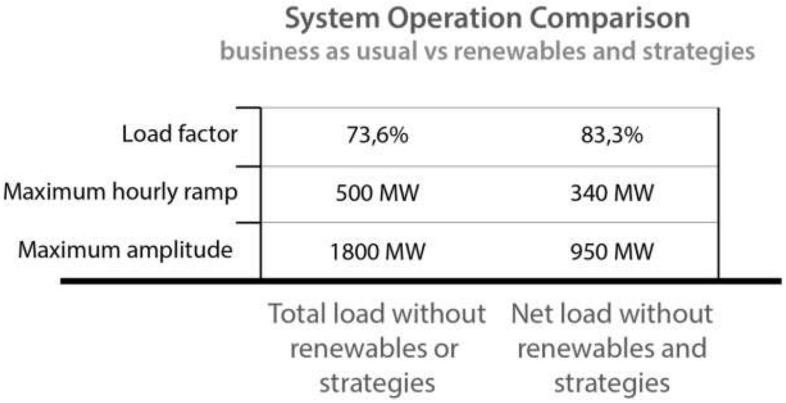
Strategy 8: Deploy electrical energy storage in targeted locations, including electric vehicle charging controls;

Strategy 9: Implement aggressive demand-response programs;

Strategy 10: Use inter-regional power transactions to take advantage of diversity in loads and resources.

In fact, when depicting the impact of the implementation of these strategies he came to the conclusion that the modified curve after applying the ten strategies could actually present management advantages, when compared to a system without the addition of renewables. “The peaks have been shaved, the valleys filled, and the net load to be served with dispatchable resources has been smoothed (…) The combination of renewables and strategies is an easier system to manage than a system without the addition of renewables”[67].

The following table shows the results on system operation with and without renewable energies and strategies.



System Operation Comparison

business as usual vs renewables and strategies

	Total load without renewables or strategies	Net load without renewables and strategies
Load factor	73,6%	83,3%
Maximum hourly ramp	500 MW	340 MW
Maximum amplitude	1800 MW	950 MW

Table 5 - System operation with and without "Duck Curve" (Source: adapted from Lazar 2014)

Similar studies were performed this time for the European context but the risk has been considered low for current conditions and penetrations levels, “The “backup” capacity has been studied in European conditions by the Intelligent Energy Europe project “PV PARITY” and has led to some costs calculations that remains rather low in European market conditions”[18].

Inspired by strategy 2, it could be an interesting approach to use the part of the backup capacity cost to finance other complementary renewables that are able to generate power in the typical ramping periods, for instance PV panels with non-ideal orientation, such as the west faced or building integrated. We can make a parallelism with the time-of-use approach, used to reflect production cost to the demand side,

4.4.3 Additional impacts

4.4.3.1 Environmental impacts

The low environmental impact of RE, when compared to conventional energy sources, is seemingly the *ex libris* feature of renewable technologies, although it is not necessarily the driving force for RE deployment. Different RE technology will present different environmental externalities, for instance a large hydro or biomass power plant is not comparable to a PV or wind power plant, where the first two are arguably not so environmentally neutral.

Nonetheless Renewable Energy sources in general are described as having no significant emissions in generation[8], as there is no fossil fuel combustion associated and therefore no net-greenhouse gas emissions.

In accordance with the scope of this work, we will focus on solar power generation technologies. Regarding the life cycle of solar technologies, the most relevant aspects to consider are:

- Land use and sitting
- Water and energy usage in component production
- Hazardous waste management

Most of the land used for larger utility-scale solar facilities, depending on their location, can raise concerns about land degradation and habitat loss. However, rooftop solar typically makes use of an otherwise useless area, thereby diverting this impact when deployed in this format.

For utility-scale solar systems land usage impacts can be minimized by siting them at lower-quality locations such as brownfields, existing transportation and transmission corridors, or abandoned mining land[70].

For water usage we should look into water consumption which is defined as the amount of water that is “evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment” (Kenny et al., 2009). This represents the water effectively removed from the ecosystem, compared to fossil fuel based technologies, or nuclear power plants, the necessary water consumption for PV is relatively insignificant, the largest water consumption associated with solar-electricity production is for CSP technologies trough cool tower plants[70].

The PV cell manufacturing process includes a number of hazardous materials, such as compounds of cadmium, selenium, and lead, and there are concerns about potential emissions at the end of a module’s useful life. Like all other technologies, solar technologies require proper waste management and recycling. To dispose of the material properly, the producers must transport it by truck or rail far from their own plants to waste facilities hundreds or, in some cases, thousands of miles away. The fossil fuels used to transport that waste are not typically considered in calculating solar’s carbon

---

[8] The case of biomass is more disputable, it is typically regarded as having an neutral overall cycle, under specific regulations, since the emissions in combustion are captured in the growth of the biomass.

footprint, giving scientists and consumers who use the measurement to gauge a product's impact on global climate change the impression that solar is cleaner than it is (Anon., 2013).

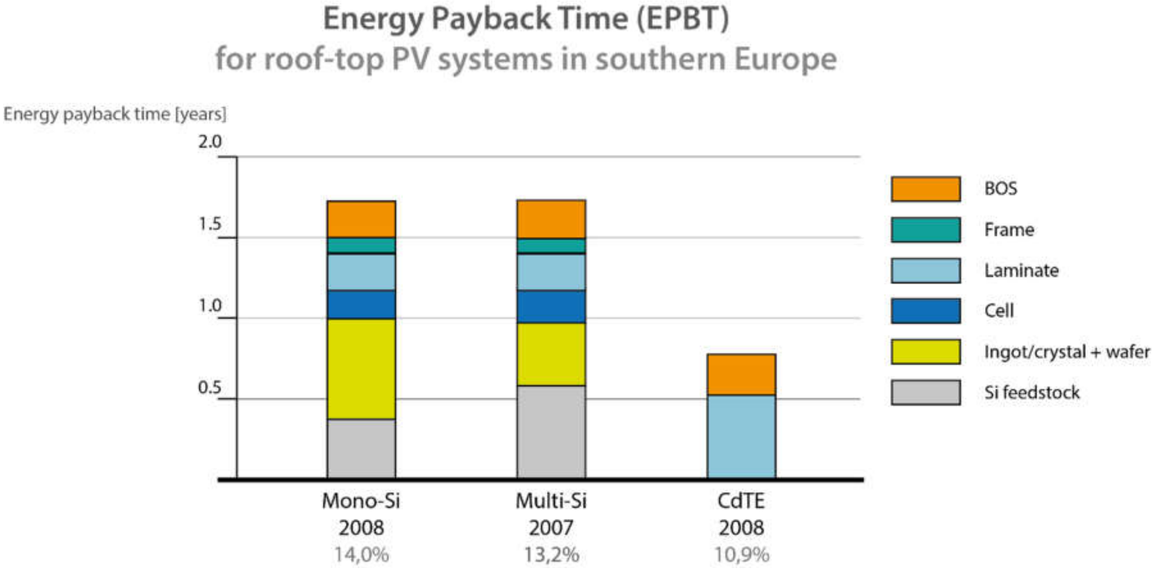


Figure 19 - Energy Payback time (EPBT) of rooftop mounted PV systems in Southern Europe (Source: adapted from IEA PVPS 2015)

In fact, when compared with conventional generation, the impacts of PV are incomparably smaller, they actually present advantages and benefits in all three aspects announced, adding to that advantages in CO2 emissions and air quality.

Energy usage for PV is almost exclusively related to component manufacturing, since the primary energy is free and the operational cost are marginal, most of the energy is spent in the crystallization of silicon (Si), this share is most significant for monocrystalline technologies. There are two important indicators to analyze these impacts, one is the energy payback period, the other is the equivalent CO^2 emissions for volume of production.

Energy payback period is the time that it takes for a device to generate energy equivalent to the energy spent during its manufacturing. Figure 19 compares these periods for different PV technologies, and the energy payback period is under 2 years, where the standard guaranteed operation time for a PV module is 25 years. These values are however out of date, the rapid evolution of the PV industry has led silicon cells to attain lower cell thickness and higher efficiency[71].

On the other hand, the equivalent CO2 emissions for volume of generation allows us to compare different technologies and sources in terms of their impact in CO2 emissions, and therefore climate change.

Renewable technologies, as predictable, will present far better results than the most advanced fossil fuel based power plants. In fact, as depicted in figure 20, lifecycle assessments (LCA) for electricity generation indicate that greenhouse gas emissions from RE technologies are, in general, significantly lower than those associated with fossil fuel options, and in a range of conditions, less than fossil fuels employing carbon capture and storage. The median values for all RE range from 4 to 46 g CO2 eq/kWh while those for fossil fuels range from 469 to 1,001 g CO2 eq/kWh (excluding land use change emissions)[72].

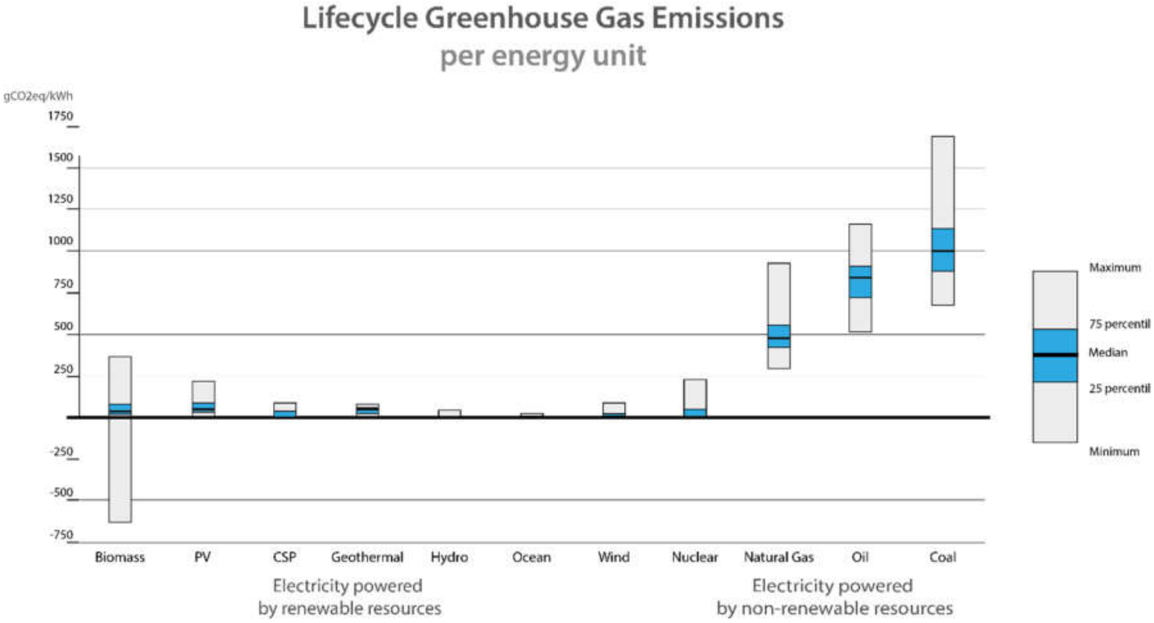


Figure 20 - Summary of life-cycle GHG emissions for power plants (Source: adapted from IPCC SRREN 2011)

Theoretically this kind of indicators could allow us to either attribute a premium for avoided environmental externalities, or inversely penalize more polluting productions technologies It is thereby usual to include a value for avoided CO2 emissions in the calculation of the value of solar power for the overall electric system.

Advocates of this compensation usually refer that the externalities caused by fossil are not internalized in the energy cost, therefore this compensation should not be seen as an incentive but as fair value.

4.4.3.2 Socio-economic benefits

Energy availability; Energy availability means that there is sufficient energy supply to meet demand at all times, as well as the infrastructure needed to transport the resource to final use. Self-consumption can make use of inexhaustible and inherently local resources, such as solar power to assure energy supply availability during periods of fuel supply disruption or geopolitical instability.

Energy affordability; Solar energy can help deliver affordable energy in places where PV LCOE has dropped below retail rates. Solar energy can also serve as a hedge against both price volatility and uncertainty. On the big picture the integration of solar energy into national energy systems can diversify the generation portfolio and help insulate national economies from changes in conventional fuel prices. The merit order effect from increased RE penetration, as previously discussed, can also benefit energy affordability.

Energy supply sustainability; The amount of fossil fuels that can be extracted will eventually be capped either by regulatory constraints (e.g. greenhouse gas regulation) or by resource exhaustion. Renewable energy will be able to continue to supply power if and when fossil fuels are no longer available or accepted.

Green growth; Self-consumption together with renewable technology development can create new and direct domestic jobs in the manufacturing, installation, and service industries, as well as indirect and induced jobs in the broader economy.

Sustainable development; Self-consumption and solar power can also create the foundation for a long-term economic development strategy that can decouple growth from natural capital depletion, in the face of environmental stress and a decrease in reliance on fossil fuel industries.

Innovation and industrial development; Along with new jobs, countries may also pursue solar power development in order to develop new industrial clusters, potentially developing intellectual property and transactional goods.

Rural development; Self-consumption can provide modern energy services to isolated areas that do not have a reliable power supply or struggle to afford their energy demand. Self-consumption, when retail parity has been crossed, can significantly improve livelihoods by creating new economic opportunities.

4.4.3.3 Tax Collector – Government

Another inevitable stakeholder of the energy system are the governmental institutions, after all they have the most important role in framework construction and regulatory decision making. However, the political and regulatory options will also induce impacts or consequences, both in tax collection and through public funding of RE programs.

An interesting example is the case of FiTs, as it is a policy incentive instrument it represents a governmental expenditure, although it is usually financed through a surcharge on electricity consumption for all consumers (the case of Germany or Portugal for instance) therefore not stressing the national budgets. Additionally, FiT revenues are normally taxed as income, also playing a part on tax collection or revenues.

Governments may therefore experience revenue loss as result of the transition from pure FiTs to self-consumption. As FiT rates decrease below the retail rate and generators may migrate to self-consumption (or as FiT rates are simply phased out), the associated tax revenues will decline. Local, state and national governments may experience erosion of tax revenues as a result of the growth of prosumers since the self-use of the energy generation is usually tax exempt.

Therefore two revenue losses are predictable for tax collector[11]:

- Revenue loss from reduced retail sales
- Revenue loss on income tax from transition from FITs to self-consumption

However according to a study conducted by IEA PVPS [18], when comparing with no regulatory framework, the net present value for the tax collector will increase in all typologies of self-consumption, with the exception of net-energy metering. This increase is due to the VAT obtained from the investment in the RES acquisition and by the corporate taxes collected from the installer, but diminished by the reduction in the energy purchased from the grid by the prosumer. Additionally, when cost recovery mechanisms are in practice, they provide the tax collector with an extra income from the taxes associated with the self-consumption fee.

4.4.3.4 Grid defection

Grid defection is usually presented as a possibly catastrophic effect of self-consumption on the public grid sustainability. It is often argued that if RE installations with storage systems reach prices below retail parity prosumers might make the option to "unplug" themselves from the grid.

A recent national study from Australia concluded that such "independence" or "defection" scenarios are not currently cost competitive, but could become an economically feasible option in the period 2030-2050 (Future Grid Forum, 2013).

A study for the United States, which takes into consideration a range of technology and electricity price trends, similarly concludes that grid defection could be broadly cost competitive across the country during the same timeframe (i.e. 2030-2050) (Bronski et al., 2014)[11]

However, it is also argued that the comfort and security of being connected to the grid, even if as a back-up solution, will not be postponed except in particular circumstances, quoting a statement made thirty year ago by EF Lindsey: "Until you've walked into a totally dark room with a flashlight in one hand and a toolbox in the other, you haven't had a firsthand experience with onsite power"[64].

If the drivers to maintain connectivity as a backup supersede the will for complete independence, then another approach could be considered in which these self-consumption systems with storage are used to provide grid services, and potentially get remunerated for such, just as conventional producers through power guarantees.

4.4.4 Final considerations

Due to the complex nature of these impacts and the correlations between different factors there is arguably no consensual or universal answer to the net-value of these impacts. Also it is important to acknowledge that these impacts can be foreseen in different time scales, from short term to long term, leading to different conclusions when regarding different periods (see figure 3), also they vary depending on the stakeholder in unbundled energy systems.

"A number of studies have attempted to assess the costs and benefits of distributed PV. The results cannot be easily compared because each study takes a different perspective or looks at a different set of variables (RMI 2013; CPUC 2013; Stanton et al. 2014)"

An interesting example of the non-linearity of the discussion is noted in the argument of grid investment relief due to DG, while this might be true in many cases for the transport network, the same thus not apply to the lower voltage levels of the distribution network that might require enhancement.

On another perspective positive effects such as the MOE could be monetized by the public authorities, and invested in infrastructures that are necessary to be built due of the introduction of renewables in the energy mix, such as grid reinforcement works or in spare peak capacities to allow peak producers to remain profitable[14].

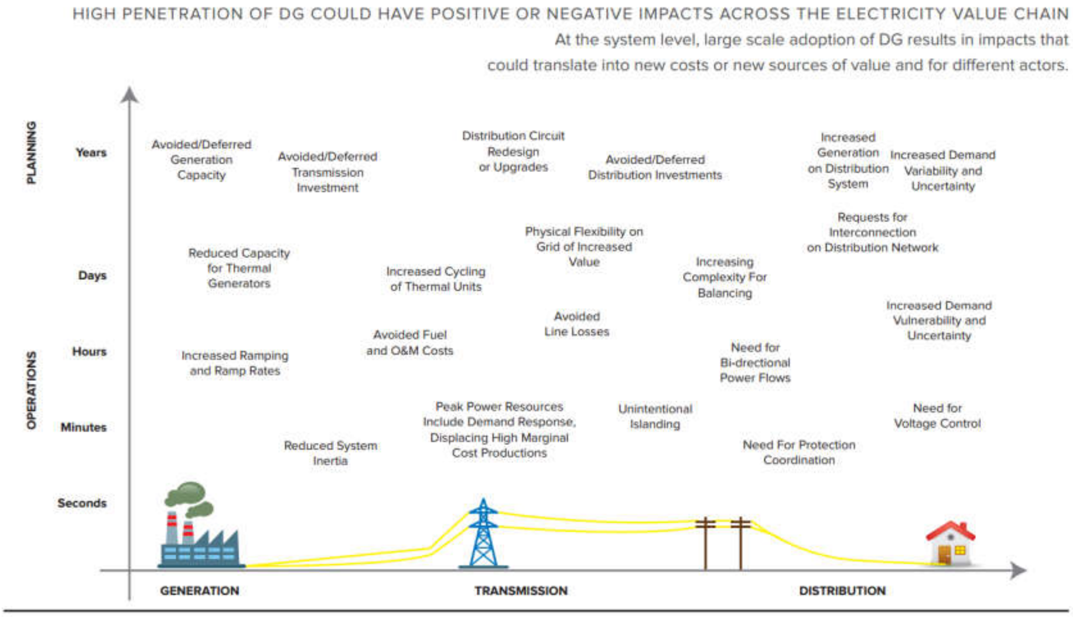


Figure 21 - Positive and Negative impacts along the electricity value chain

This discussion has originated antagonistic views over the theme, the USA can be seen as an example of why in circumstances where the interest of all stakeholders are not taken to consideration we face the risk of a polarization of the debate, the attractiveness and consequential market expansion under net-energy metering led to a situation where “a growing number of utilities have recently proposed adding demand charges, standby charges, or flat monthly fees on the bills of residential customers with rooftop solar, or putting solar customers into a separate rate class with different rates than other residential customers.” This is demonstrated by the fact that “in 2015, there were 21 pending or decided utility proposals to add or increase solar charges in 13 states”[32].

While no univocal answer can be provided to the question of the net-value of DG, it is certainly recommended that this analysis is made on a case specific basis regarding:

- Location, grid features and needs
- Stakeholders separation (vertically owned utility *versus* unbundled energy system)
- Export remuneration mechanisms
- Adoption rates and penetration levels

The last two will ultimately be interdependent. As export remuneration mechanisms can lead to market distortion and “artificial” adoption rates. As verified in the initial assessment, export remuneration mechanisms can vary from no value, to avoided cost valuations linked to wholesale market prices, or even to “value of solar” propositions that go above retail electricity prices (see value of solar discussion at USA).

4.5 Strategies and solutions to minimize

4.5.1 Updating grid charges through innovative rate design

Rate design and respective grid charges need to be well adapted to the existing reality and actively respond to sector transformations, in order to provide a sustainable long-term path for the overall energy system.

Overall, “the effectiveness of a utility’s role in conducting the orchestra of distributed energy resources that interact with its system will be a critical factor in achieving favorable outcomes for all stakeholders. And the long-term health and stability of the electricity grid will be essential to making such a system work”[13].

This is an especially important topic in order to guarantee that the “cost-of-service” provided by the energy system is recovered, and also to give the correct price signals that indicate the strategic path we wish to pursue. It should be underline that it helps to promote a stable integration not only of DG, but also electric vehicles and smart grids.

The compensation for the loss in grid charges, or the need for extraordinary investments in the existing infrastructure to deal with distributed generation, can be enforced through several measures, and should account that there are also positive effects. Although this is topic is not the focus of this work, it is considered indissociably from self-consumption policies as the regulatory assessment previously conducted tends to prove. Some general considerations in this issue will thereby be made, and some trends evidenced, to allow a more holistic concept analysis.

Cost recovery mechanisms exist in several forms (refer to figure 18), be it though a tariff on volume, demand (capacity) or fixed periodic charges, applied transversally to all grid users or specifically on prosumers, or even no cost recovery at all. There is no standard approach across borders on how to employ these measures and they are not limited to those depicted in this work.

One of the cost recovery options can be the increase of existing volumetric rates on all consumers, persisting with the traditional model, however what we know is that this methodology can further aggravate the effect of cost shifting, since prosumers normally import less energy, therefore paying even less charges comparatively to regular users.

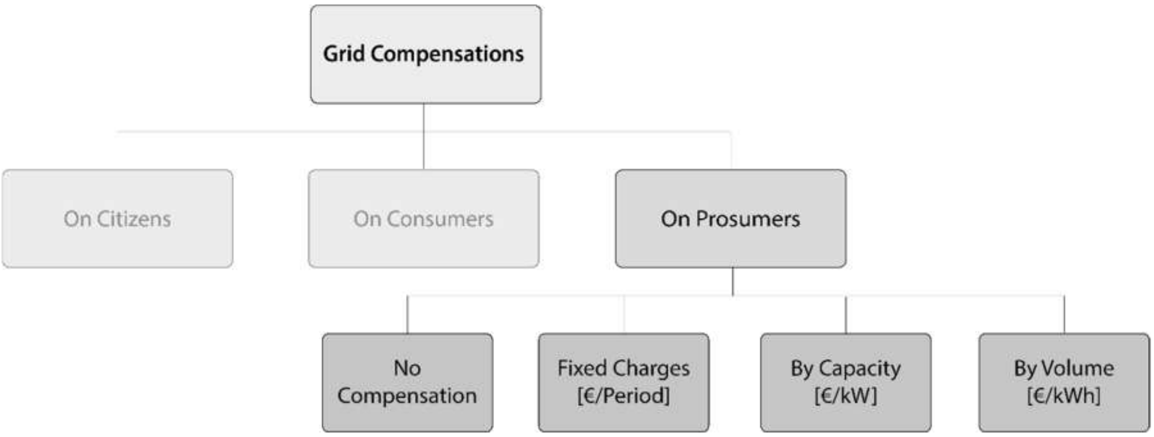


Figure 22 - Usual Grid Compensation Mechanisms applied to Prosumers (Source: Author)

For that reason and for other factors already mentioned, such as consumption stagnation patterns, it is rather consensually argued and accepted that there is a need for decoupling of energy related revenues and charges, for both grid operators and energy suppliers, in unbundled system scenarios. However, there is a considerable conundrum associated with energy revenue decoupling, as it will also affect the energy savings provided by self-consumption.

Moreover, it is fairly safe to assume that any rate design transformations should avoid, or be cautious, in the use of transversal volumetric charges. A usual alternative proposition has been the increase of fixed charges, however if this is made across all energy consumer the argument of cost shifting between users is again "on the table".

Alternatively, to cover the grid financing losses, some countries have imposed (or are discussing the introduction of) specific fees per capacity (kW) of installed PV or per volume (kWh) of self-consumption. Charges ought to be designed to make the business model of the grid and utilities compatible with that of prosumers[18]. If we opt to transfer this cost to the prosumer, we need to address it as a two-way stream, recognizing the need to compensate eventual losses for the grid, while also avoiding to over damage self-consumption's economic viability and therefore the policy's deployment rate.

"In developing new rate structures, utilities will be forced to reexamine the fundamental elements of the "cost to serve" (i.e. capacity related fixed costs, non-capacity-related fixed costs and variable costs) and the allocation of these costs as they pertain to customer-generators"[13].

Some authors also advocate that price signals should be sent to allow that all system agents are able to provide benefits to the system management. "Retail pricing mechanisms that substitute volumetric charges and single fixed charges can be designed to help utilities fully recover the costs of serving their customers in high DG penetration scenarios. These include demand charges, real-time and time-of-use rates, and attribute unbundling"[31].

Time of use mechanisms can be particularly important to send accurate price signals for electricity users, allowing them to shift consumption and alleviate the system in peak consumption hours.

Additionally, prosumers could also control their load and install their systems in a way that benefits the grid.

Recognizing that not all users are the same is fundamental for this process, and it is not something that new for the sector. Typically, ratemaking differs by capacity scales or voltage levels already. For instance, an industrial consumer connected to high tension lines will have a different cost allocation than a residential consumer, since the first does not use the distribution network, but on the other hand puts a bigger stress on demand capacity. However, this distinction needs to be updated to acknowledge also that some users are not only consumers, but prosumers, with many defending that further costumer segmentation is needed.

“To equitably distribute costs, a utility cannot simply levy energy, demand, and customer charges equally across all customers. This would require individual customers to be charged for the cost to provide them with service, and also compensated for any value that they create”[13].

Certainly this cannot be done at a case by case basis, but different typologies of users, different regional needs and grid fragilities or specificities can be used to further approximate grid charges to the real grid cost of service. The regulator figure can therefore have an important part in a value based ratemaking future.

If such is not the case, there is a growing possibility that these perspective differences from stakeholders can lead to an prolonged and polarized conflict over self-consumption policies. The Rocky Mountain Institute organized a think tank with both USA’s utilities and energy experts to debate and analyze this situation, especially opportune due to the country controversial net-energy metering approach to self-consumption. They came to the conclusion that “Ultimately, it is important to find common ground among these different views in order to devise a sustainable electricity system that includes higher penetrations of distributed and renewable supplies while maintaining a healthy and reliable grid"[13].

Also identifying three basic issues that should be addressed:

- Identify, measure and communicate impacts, costs and values;
- Remedy misalignments through innovative pricing models;
- Adapt retailers’ and generators’ business models to create and sustain value.

4.5.2 Price signals through ratemaking of energy export

Surplus generation export mechanisms can also send signals to self-consumption promoters, that will significantly impact how the system is sized and deployed, or alternatively grid charges can be set to impact only the surplus share of the generation.

If the surplus generation valuation is high, for example at retail rate or above systems LCOE, we will often see higher adoption rates and systems sized at least to match yearly consumption values. This can lead to an increase of revenue erosion from the grid financing perspective in net-energy metering scenarios, or to an increase of grid injection in general.

If the surplus valuation is low, for example under the LCOE of the system, it may cripple self-consumption adoption and systems will most likely be sized to match the instantaneous demand profile instead of the annual one. Renewable promoters will usually defend that the remuneration underfinances the energy cost and blocks superior RE deployment, (see the Spanish example and the so called “tariff on the sun”). But on the other hand, energy exports will be minimized, and with so the grid impacts associated to them.

There are two interconnected optics here, one is the political option to incentivize or not RE technologies, the other is sending the correct price signals that guide the market in line with strategic options, such as grid sustainability.

This is therefore a sensitive issue in the author’s opinion, if the valuation is low, there is an inherent price signal to avoid export, and therefore no grid compensation should necessarily be imposed on surplus generation. On the other hand, if valuation is high but properly sized not to overvalue systems energy costs, it is then contradictory to charge prosumers for grid compensations, as we are giving with on hand and taking with the other.

Due to current low levels of prosumer penetration in the electric system, a seemingly intelligent approach would be to set grid charges only when surplus generation penetration is considered

detrimental for the overall energy system. This would therefore need case by case analysis, of the net value of these impacts and, in case they are negative, above what level of penetration they would be felt.

4.5.3 Optimizing the self-consumption ratio

The need for optimizing the self-consumption ratio (i.e. the percentage of self-generation that directly offsets energy import from the grid, arises from several motivations, most of them already mentioned in previous chapters, such as:

- Regulatory constraints and signals to diminish energy export and respective impacts, even if the discussion over the net value of these impacts is yet to be conclusive.
- Decreased economical appeal for energy export as surplus remuneration values fall below retail price, aggravated when the remuneration goes below the actual LCOE of the RES.

In frameworks with low surplus generation rates, such as market integration, a high match between production and consumption is automatically promoted[73].

Even though this is not the case in every jurisdiction, there is an overall tendency to decrease excess generation remuneration, to values beneath retail electricity rate, tendentially towards wholesale market price levels, which represents values bellow the present LCOE of a small scale or residential system. Even if surplus remuneration rates are superior to the systems LCOE, if this value is under the retail rate there is still an economical advantage in preferring self-consumption if possible, since the energy savings will be superior to the export remuneration. Whatever may the case be, there are advantages for both prosumers and grid operators to maximize the self-consumption ratio, the self-use of instantaneous generation in detriment of energy export.

If we look to residential consumers, guaranteeing a high self-consumption ratio is particularly complicated. Typical commercial or industrial load profiles present significant base loads and consumption activity during sunshine hours. On the other hand, residential buildings will often have extremely variable consumption levels, with very low demand during the day-time, namely because this is the period when occupants are off to work or education. Therefore, instantaneous load matching of consumption and generation is pointed as much more promising for industrial or commercial purposes, while most literature point a maximum self-consumption ratio of 40% for residential users [11].

To increase this share, users will need to either actively transform their load profile or store excess production to use it when it is not available instantaneously. The following strategies and technical solutions are the most commonly referenced ideas to addressing this problem. This does not mean however that they have reached the maturity to be economically viable or simple feasible. Some usual strategies to optimize the self-consumption ratio are:

1. Electrochemical storage
2. Thermal storage
3. Energy vector and fuel cells
4. Electric vehicles
5. Demand side-management

This trend is leading prosumers, researchers and manufacturers to find new ways to manage their energy generation, in order to avoid grid-injection, through improved system sizing focusing on load matching, demand-side management strategies or additional equipment such as storage systems.

4.5.3.1 Energy storage

Energy storage is the long awaited ally for renewable energies to help solve resource variability issues. This is not only associated with self-consumption, but becomes particularly with market integration. The use of the battery benefits both the users and the grid utility, the users maximize the use of their production through energy savings, and the use of the battery will reduce the impact on the grid of the PV-system through grid-injection. When the yearly generation is equal to the yearly demand, the average power demand from the grid can be reduced up to approximately 40% (i.e. increases self-sufficiency), and the average power fed into the grid can be reduced up to 50% (i.e. increases self-consumption) compared to a PV-system without batteries [74].

When we think of energy storage the first thing to come to mind are electrochemical batteries such as the ones in our devices, lithium ion, or the ones in our cars, acid-lead. However electrochemical batteries still have high capital costs. Energy can also be stored in many other forms, from raising potential energy in physical or fluid masses, storing energy in a thermal form, using it to create energy vectors such as hydrogen or compressed gas, or even through a synergic use of other technologies such as the electrical vehicle, initially meant to serve alternative purposes.

4.5.3.2 Electrochemical storage

Most of these technologies are yet to provide a financially attractive solution for regular prosumers. The LCOE of a rooftop PV system with storage is, at most, close to retail price of energy, therefore the potential savings are scarce, and the initial capital investment significantly higher, blocking this opportunity for moderate and low income consumers, or even high income consumers without a motivational driver other than economic viability.

4.5.3.3 Thermal storage

Thermal storage equipment is also available in the market, even for residential users. Most of these solutions operate through a simple principle, diverting excess energy production to supply heating needs, offsetting electricity purchase from the grid. This can be done by activating the domestic hot water heater in times of surplus production, or channeling this excess energy to resistance based heaters.

While some interest can exist in these technologies and some manufacturers are developing applications in this area, they are still particularly useful in colder climates, and could in certain cases overlap with existing solar thermal systems.

4.5.3.4 Demand side management

Demand side management typically works through a behavioral transformation of users’ consumption patterns, shifting energy loads to match the RES generation curve, or to go in line with price signals in electricity rates. Due to the noticeable difficulties in changing user behaviors, and to guarantee that comfort levels are not disturbed, research on demand side management has focused on information technologies and internet of things to provide the tools and applications that make demand response possible at the lowest effort.

While we could certainly state that demand side management and smart prosumers will have their fair share in optimizing self-consumption, the concept has practical limitations since not every load can be shifted. In fact, usually there is a limited number of manageable devices, such as washing machines, heating and cooling equipment.

4.5.4 Final considerations

“The generation of onsite power is not in itself flawed; rather, the problem is rooted in the underlying rate structure“[13].

Moreover, traditional rates do not induce the correct price signals that incent the customer to provide the greatest possible value to the electricity system either in their behavior or in the RE system set up. Time-of-use electricity rates are a common example of a mechanism that could lead to positive user demand response.

“Also rate structures and incentives designed to stimulate the early adoption and scale-up of rooftop solar systems, electric vehicles, and other new technologies and design approaches will need to be modified over time, as adoption rates increase”[13]. In that sense, traditional subsidized policies need to transition to market integrated policy versions, which are able to provide a greater long term stability to the sector.

Underlying all this is the fair notion that, to an extent, self-consumption can be seen as a citizen right to use a technology that is accessible to them, if given a sustainable regulatory framework, and therefore self-consumption policies ought to be compulsively developed in every jurisdiction.

Some brief considerations can be pointed out, in order to provide long term stability to the sector:

- Prosumers shouldn’t pay for revenue erosion in the long run, the system should adapt to current and future conditions through rate designs and business model innovation. It is widely accepted that suppliers should decouple their revenue from energy sales, and similarly system charges should follow the same path. Blaming prosumers through dedicated charges to minimize this effect will not provide any additional sustainability to the system in the long run; furthermore, it fails to envision a positive integration of distributed generation and its potential benefits to the grid.

- Prosumers should however pay for their cost on the required system improvements and back-up guarantees (the technical impacts). It should nonetheless be based on a real cost of impact evaluation, and deducted of benefits provided to the grid. Nonetheless for equity reasons, other contributors for these impacts should also assume, or be charged, for their share of responsibilities.

- It would make sense to partly associate these compensations with energy export more than capacity (since a 100% self-use system does not provoke significant impact), thus rewarding demand management from users.

- Also the impact of prosumers is usually only significant after a certain level of RE penetration, and that should be taken to consideration in policy design. The Portuguese legislation is a good example where compensation charges only roll-out after a certain level of PV penetration.

- Research on the impact of DG should continue to be developed, preferably considering a regional grid evaluation. This issue is far from reaching a consensus, and there is a need to avoid the polarization of discussion through research evidence and best practices. Especially important to commit all stakeholders with environmental goals.

- Compensating PV customers more accurately for the services their systems provide could send an economic signal to encourage PV owners to install and operate their systems in a way that benefits the broader electricity system[31].

The hysteria around the benefits or prejudices of RE should be resolved with information and quantitative impact assessment, including the pros and the cons of such systems.

4.6 Conclusions on concept analysis

The drivers for self-consumption are seemingly falling into pace, with technology cost reductions and electricity rates as benchmark indicators (as seen in section 4.1). Self-consumption regimes can serve as a transition policy in the phasing out of RE subsidies, but also in the long term, as the straightforward format is likely to still be present once DG markets have matured. The IEA considers that such drivers alone are unlikely to "revolutionize" the energy field in the next few years without an enabling policy framework in place. Nonetheless regulators and decision maker ought to anticipate and prepare for paradigm shifts in energy managements.

If the trend for market liberalization remains, self-consumption is a seemingly natural right with increasing available technologies that allow end users to self-generate. As with other products regulations should be set to certificate the quality and safety of such systems. It is predictable that the two main issues that will surround the self-consumption policy theme are:

1. **Export remuneration mechanisms**; how the value is set for surplus generation fed into the grid (as seen in section 4.3)
2. **Grid compensation mechanisms**; to cover the impact, or fair share, of such systems in the overall electricity system;

Export remuneration can significantly impact investment attractiveness, and therefore deployment rates, it can also carry a symbolic sign of weather there is a national incentive, constraint or neutrality towards distributed renewable energy systems (refer to section 4.3.5). Export remuneration can also provide price signals that are market responsive, in order to decrease minimize grid impacts, and potentially even provide grid services. Nonetheless it is grid compensation evaluations that opens a wider field for numerous future researches, research and quantitative modeling will be fundamental to support conscious regulatory decisions. Such is the case of the monetary impact of self-consumption to the energy system and its different stakeholders, this work concluded that there is no consensual answer towards there being a positive or negative net impact of self-consumption (refer to section 4.4.4), this valuation should be developed on a case by case approach as there a high dependency on local conditions, such as:

1. Infrastructure and stakeholder specificities;
2. Policy and regulatory frameworks;
3. Impacts considered in the valuation;

While the grid and market technology impacts seemingly point towards a positive overall contribution[9] from DG in reducing energy costs (for instance the MOE), and potentially deferring network costs and decreasing network losses, public subsidies can neutralize or even invert this effect, assuming they are passed to end consumers through energy surcharges. Case by case macro-scenario modeling could be crucial to setting a fair balance between impacts and incentives.

Revenue erosion of grid financing is an unavoidably issue, aggravated by increasing self-consumption ratios, nonetheless specific charges on prosumers or their self-consumed share of electricity are here considered as a fragile measure, potentially hindering self-consumption diffusion, in order to deal with an intrinsic problem the energy system is facing that is not only accountable to self-consumption but also to other trends such as energy efficiency (as discussed in section 4.4.1.1). On the long term grid financing charges will need to adapt to reality changes in consumer behavior and demand, particularly in scenarios where consumption stagnates or even decreases. Balancing of volumetric and fixed charges ought to be fine-tuned to this paradigm change, minimum bill or standby charges are options that increase the fixed share of grid funding, while volumetric charges are easily offset by prosumers increasing cost-shift. If specific charges are set on prosumers these should account for the positive contributions of such systems, particularly in market integrated scenarios.

In the path towards the phasing out of subsidies for surplus generation, the issue of load matching between the consumer's demand profile, and the system's generation profile, will be evermore present. With decreasing remuneration for surplus generation, prosumers benefit from making a direct use of their production to increase their self-consumption ratio. Typically, this is done through optimization strategies such as additional storage systems and demand side management initiatives, nonetheless at present, short and mid-term, these options are limited, or not cost effective, for the majority of scenarios (refer to section 4.4.3.4 or 4.5.3).

Figure 23 summarizes the issues discussed throughout the conceptual analysis in a SWOT analysis. The SWOT analysis tool allows us to classify potential strengths, weaknesses, opportunities and threats, to society and energy systems.

The following chapter will look into enhancements to self-consumption policy design that could foster benefits for all stakeholders, through prosumer aggregation policies. These policies could potentially achieve similar benefits to those of self-consumption ratio optimization without the need for complementary technology (i.e. storage systems), while at the same time mitigate grid underfinancing effects, contraposing to possible "grid defection" scenarios. They can also create the conditions for a wider potential market to access self-consumption policy, contributing for the democratization of the mechanism.

---

[9] There are nonetheless challenges and necessary grid reinforcements, particularly in distribution networks, but these could also be seen as synergetic with grid upgrades

Figure 23 - SWOT analysis of Self-Consumption Policies (Source: Author)

Chapter 5 - Prosumer aggregation policies

The final chapter of this research conducts an assessment and evaluation focused on existing prosumer aggregation policies. A prosumer aggregation policy, terminology proposed by this research, is a broad term that aims at including distinct policies under several nomenclatures. A prosumer aggregation policy is summarized as a regulatory framework that allows for several electricity users to be associated under the same renewable energy system(s), sharing or trading the benefits of the output production through diverse formats. The author's choice to implement a new terminology was to avoid limiting the scope of how this aggregation policy is configured and defined, therefore due to heterogenic existing policies formats and labelling we opted to create a broad policy class to encompass these different experiences.

Within prosumer aggregation policies we have concepts such as peer-to-peer energy trading and shared generation, which usually work under a mechanism called virtual metering or remote metering. In this chapter we will also look into innovative ideas such as collective ownership models and DG retail aggregation platforms, sprouting with new legal frameworks or by working around existing ones, which may disrupt traditional utility's business models.

These regulatory mechanisms, and business models within, can present variable aspects in terms of system ownership, system location (on/off-site; after/behind-the-meter), number of parties involved, profit or non-profit relation, etc. Such regulatory initiatives can be seen as enhancements to existing self-consumption policy approaches. They contrapose traditional self-consumption policy structure, in terms of regulation, which generally foresee one RES per consumption installation, or a behind-the-meter grid-connection that induces "physical" self-consumption and only excess generation exported to the grid, also usually they establish a standard or unique model for excess energy remuneration.

Four main questions regarding prosumer aggregation policies were considered relevant to serve as motivation for the work developed:

- Could prosumer aggregation policies help accelerate self-consumption diffusion and increase the potential market?
- Could prosumer aggregation policies help improve socio-economic or technical drivers for self-consumption?
- Are prosumer aggregation policies compatible with the energy systems frameworks and its trends?
- Could citizen cooperation in energy generation and management be seen as a civil right, such as the right to self-consume?

Considering that as seen in chapter 4,

1. the adoption of self-consumption is still constrained to a large share of the population due to local conditions;
2. the optimization of the self-consumption ratio still faces unavoidable limitations, be it on a technical, economic or behavioral level;

3. the export values of market integrated regulatory trends, often underfinances the generation cost of a small scale system, at present technology prices.

there could be advantages in developing innovative regulatory mechanisms such as prosumer aggregation policies to address these issues, without having to wait for technology developments in generation or storage

The following chapter presents the results of the international assessment and literature review. The two concepts mentioned earlier, peer-to-peer energy trading and shared generation, were repeatedly identified throughout the literature review. Shared generation is also known as solar sharing or community renewables. An analysis on these concepts is conducted in section 5.1.3 and 5.1.2 respectively. On the other hand, virtual metering, remote metering, tenant aggregation, meter aggregation and community solar gardens refer to actual regulations and policies, reviewed in section 5.1.1.

5.1 International context and aggregation concepts

The vast majority of DG regulations for RES do not present any provisions regarding prosumer aggregation, if we refer to the policy assessment presented in chapter 3, many legislations in fact explicitly forbid it. That can also be implicitly regulated by requiring the system to be built on-site or behind-the-meter, or by limiting participation on a one-to-one basis in terms generation system and consumption point. Nonetheless there is a group of examples and experiences around the globe which can bring some light to this theme, also allowing us to draw some conclusions and build a solid way forward.

When searching further into examples of public policy approaches for prosumer aggregation policies, the first step was to look into USA's and European initiatives, as they present what are considered the most advanced public policies in terms of RE and DG.

According to the research conducted, the USA have the widest set of mechanisms that regulate prosumer aggregation activities within Self-Consumption. 16 States have enacted some sort of virtual metering policy, or in a more precisely terminology, virtual net metering in NEM contexts [38]. Perhaps contrary to what expected Europe does not present as many examples of regulatory provisions for prosumer aggregation as other parts of the world. Most of the aggregation initiatives in Europe have been made informally through the RE cooperative movement (section 5.1.20).

5.1.1 Prosumer aggregation regulations

It is possible to identify several aggregation policy mechanisms, whose regulatory frameworks present slight differences between countries or states as their formats and terminologies are not standardized or used consistently. Also these programs are in some cases restricted to certain utilities or costumer types. The assessment conducted pinpointed the following types of public policy instruments, regulatory instruments to be more precise:

Aggregate net metering; meter aggregation or basic meter aggregation; are defined as a net metering arrangement that allows for a single generating system to be used to offset electricity use on multiple meters, without necessarily requiring a physical connection between the system and those meters. In this format it is required for the customers' meters to belong to a single entity, and be located on a single property or contiguous properties. How contiguous is legally defined is therefore an important factor, a simple example of this importance can be understood by a situation where a potential user has properties located on either side of a street. Aggregate net-metering is therefore an interesting arrangement for multi-meter properties, application examples can go from farms, hotel industry, public buildings, military facilities, to regular private properties[33].

Some examples of USA states who explicitly allow for aggregate metering are Arkansas, California, Colorado, District of Columbia, Delaware, Illinois, Minnesota, Nevada, Oregon, Rhode Island and Utah[33].

Multi-site aggregation is an example of terminology variations, this one is used in cases where meter aggregation is allowed for a single entity with meters which are not located in nearby sites, the regulation is, in this case, called. The states who have expanded meter aggregation to this format are California, Delaware, Maryland, New York, Pennsylvania, Rhode Island, Washington and West Virginia[33].

Tenant aggregation is a similar concept, the only difference being that in this case more than one entity can be registered under the same RES. This is most relevant for multi-family residential buildings and other multitenant buildings (e.g., a shopping mall or office building complex) where individual meters are owned by different customers instead of a landlord. A residential "neighborhood" system may also be able to utilize Tenant Aggregation.

California is the only state which has enacted this particular mechanism[33].

Virtual net-metering (VNM) is the regulation that allows for the broadest expansion of prosumer aggregation arrangements identified during this research. VNM allows several customers to participate in meter aggregation even if they are located on non-contiguous properties, or in case the RES are located off-site, or jointly benefit from shared generation system. Identic or similar programs were found under different terminologies such as shared solar or community solar gardens, depending on the jurisdiction [75]. It is arguable that virtual net-metering could comprehend the former mechanisms reported, nonetheless some legislators have opted not to allow full virtual net metering, preferring one of the more constrained mechanisms enounced.

Some examples of USA states who enacted virtual metering provisions are, California, Colorado, Connecticut, Delaware, Hawaii, Maine, Maryland, Massachusetts, Minnesota, New Hampshire, New York, Vermont, Washington D.C.[75].

Other countries however have enacted similar regimes, for example Brazil's Remote Self-Consumption provisions ("*Autoconsumo Remoto*"), also based on a NEM scheme, allows prosumers to transfer their excess generation credits to other consumption points from the same entity, under the same utility. Additionally, the Brazilian government has established the shared generation figure *("Geração Partilhada"),* that allows for citizens to join in an organization, or cooperative, to develop a common RE installation and use the generation to reduce the investors utility bills[76].

Israel also has a NEM regime and has made virtual net metering possible by enacting a regulation where one consumer is able to transfer credits to another and the credit will be offset from his bill. Honi Kabalo, head of the renewable energy field mentions, in the Public Utilities Authority and Electricity regulator, that this option is rather exceptional to a consumer-based regulation. It is intended to reduce risks and increase bankability of the RES, by ensuring the possibility to use and refund electricity produced in the RES even in case of permanent decline in consumption (e.g. factory closed, household consumption declined over the years etc).

In Mexico a virtual net-metering system exists for large installations, with the possibility to net electricity consumption and production at distant sites[5]. They have also established a wheeling charge for compensating the use of the grid.

The Greek prime minister Alexis Tsipras also announced, in 2016, the roll out of a virtual net metering plan after the Orthodox Easter break, when a ministerial decision is expected to be signed to bring the measure into effect, initially for farmers, and subsequently to all users[10].

As abovementioned virtual net-metering can be enhanced or restrained to several formats, potentially including the former instruments presented. Hence, it is here considered the most relevant regulatory mechanism for prosumer aggregation under self-consumption regimes at the present moment, notwithstanding, as seen in the assessment virtual net-metering is closely tied with net-energy metering regulations, assuming a 1:1 retail valuation of all generation and energy credits. This work will propose a virtual metering terminology (VM), as opposed to virtual net-metering (VNM), to remain policy neutral. This neutrality will lead to mandatory additional regulatory provisions that are simplified in net-energy metering regimes, were the use of the grid is typically free, and surplus energy turns into retail energy credits, examined in section 5.3.

Australia is testing a virtual metering concept with five pilot projects rollout in 2015, outside of a net-energy metering regime. The aim of these projects to facilitate the introduction of reduced local network charges for partial use of the electricity network, and the introduction of local electricity trading between associated customers and generators in the same local distribution area[39]. Local electricity trading was, in this case, the terminology used in preference of virtual metering.

Local electricity trading mechanisms where envisions to allow for different metering configurations:

- A single generator-customer can transfer generation to another meter(s) owned by the same entity (e.g. a Council has space for solar PV at one site and demand for renewable energy at a nearby facility);
- A generator-customer can transfer or sell exported generation to another nearby site;
- Community-owned renewable energy generators can transfer generation to local community member shareholders;
- Aggregators (e.g. retailers) can purchase exported electricity from individual generators and resell it on the energy market or to local customers[39].

---

[10] http://pv-spyropoulos.gr/index.php/en/blog/item/1121-ypografetai-i-ypourgiki-apofasi-gia-virtual-net-metering-arxi-me-tous-agrotes

In the UK, OFGEN, the grid operator, together with Open Utility, an private company in information technologies for energy businesses and Green Energy, a retailer that only commercializes renewable electricity, have joined forces to conduct a 6 month pilot test of an energy market with virtual metering, that also enacted local network charges (the Piclo case study, section 5.3.1).

5.1.2 Shared generation

"Shared solar programs offer a convenient and cost-effective option to utility customers who want to buy electricity from a low-carbon, renewable resource"[58].

The shared generation concept is also referred to as solar sharing, community solar, community renewables or community solar gardens. Shared generation is a term used to describe a model where different participating entities share the output of an RES; tenant aggregation or virtual metering can be used to regulate such systems in self-consumption regimes, although not exclusively as we will discuss ahead.

These systems can be developed both on-site or off-site[11] and have the advantage of presenting some features of economies of scale. The terminology was popularized in the USA, "shared solar models allocate the electricity of a jointly owned or leased system to offset individual consumers' electricity bills, allowing multiple energy consumers to share the benefits of a single solar array"[37].

Shared generation systems can be hosted and administered by a variety of entities, including utilities, solar developers, residential or commercial landlords, community and nonprofit organizations, or a combination thereof. The benefits of the produced electricity are typically allocated to investors on a capacity or energy basis. Participants in capacity-based programs own, lease, or subscribe to a specified number of panels or a portion of the system and typically receive electricity or monetary credits in proportion to their share of the project[37].

Within shared generation policies we can find programs such as Colorado's Community Solar Gardens[77], where groups of at least 4 citizens can join to deploy their own collective RES, and split the energy produced perceptually in a pre-arranged manor.

The shared generation concept also exists outside self-consumption regimes, such as feed-in tariff regimes for instance. Here the output energy from the shared system is used to generate a cash flow rather than offsetting energy use and lowering electricity bills. Such is usually the model of the RE cooperative movement and RE crowdfunded investments, particularly widespread in European countries, where the scheme is often analyzed as a financial investment. We can take as an examples Denmark where 85% of wind power is owned by the residents of Danish communities, or Germany where 47% of RE generation is in the hand of citizens or cooperatives[38].

But with European policies moving towards self-consumption and the phasing-out of RE incentives these cooperative business models are being reinvented to adapt to present reality and regulatory

---

[11] Although there usually exist restrictions on this matter

frameworks, we will look into how they transformed their business models in the case studies ahead (the SOM energia study case, section 5.3.3).

The Danish case can be traced back to the 1980s, where Danish families were offered tax incentives for generating power for their community. As a result, more and more wind turbine cooperatives started to invest in community owned wind turbines. By 1996, there were around 2100 cooperatives throughout the country, which created the basis for continuing popular support for wind power in Denmark. By 2001, wind turbine cooperatives, including more than 100,000 families, had installed 86% of all turbines in Denmark. The 1996 Energy Plan aimed at creating an energy sector rooted in a “democratic, consumer-oriented structure”. Cooperatives have played an important role in the development of wind power by helping create public acceptance. Their engagement has ensured that communities directly benefitted from wind power development, especially in the form of profit-sharing from electricity generation from renewable energy sources and from lower energy taxes. The planning responsibility for offshore wind farms is currently managed at government level, while the planning of onshore wind farms is collaborative[78]. The Danish example can be seen as a successful model to democratize access to subsidized renewable policies, through the shared generation concepts. The investment for wind farms initially came from individuals through cooperatives. However, as turbines became larger, the size of the projects increased, requiring private sector investment. Small individual developers have difficulties in investing in large projects, due to the initial capital required. Offshore projects are for the same reason mostly financed by utilities.

The European federation for renewable energy cooperatives (REScoop) is an example of the cooperative movement’s maturity in the European market, it join a network of 1250 European RE cooperatives and more than 650 000 citizens. They include relatively small cooperatives, with few members that pursue only small-scale renewable projects, to large cooperatives such as Belgium’s Ecopower, with more than 50 000 members, owning 17 wind turbines, 3 hydro powers installations, 320 solar PV plants, and 1 cogeneration plant that uses rape seed oil[79].

Shared generation can be categorized according to their ownership model, J. Farrell suggest to do so co as shared renewables and community owned[38]. Where community-owned models are usually collectively owned by a community or an organization created for this purpose, and shared renewables usually governed by a third party or utility. These two groups are not completely distinct and some hybrid models do exist. Traditionally community-owned models would be the regarded more as a financial investment and shared renewables as the mechanism to off-set energy purchase and generate savings.

A range of stakeholders have touted shared solar as a middle ground in stabilizing the customer-utility relationship, while addressing equity concerns on the customer side and revenue concerns on the utility side[80].

5.1.3 Peer-to-peer energy trading

The peer-to-peer (P2P) energy trading concept assumes prosumers could likewise aspire to individually be an active part of a network that links prosumer, consumers and energy producers, to provide a desired service. The increasing popularity of P2P systems is due to the ability of such systems to combine resource contributions from individual peers into a large shared pool of resources.

This concept refers to an energy trade that could be done bilaterally or multilaterally. This could be done through regulations such as virtual metering and goes in line with a more active participation of citizens in the energy market, and the "digitalization" of the electricity system.

The terminology is seemingly inspired by the peer-to-peer computing concept. P2P computing is a paradigm in which resources (e.g., storage, CPU cycles, and data) from a numerous number of end systems (peers) are combined into a shared pool. Peers are connected through a virtual overlay network[81].

A parallelism can be established between both concepts, since both the internet and electricity, are related to a service sector which is dependent on a utility grid. Although this comparison can only be reasonable to a degree, the similarities are evident even in some of the possible features and services procured. Notice for instance when hailing P2P in computing applications it is often referred as "a promising technology that will reconstruct the architecture of distributed computing (or even that of the Internet)". The same could be put to distributed generation and its impact on the overall energy system. "This is because it can harness various resources (including computation, storage and bandwidth) at the edge of the Internet, with lower cost of ownership, and at the same time enjoy many desirable features (e.g., scalability, autonomy, etc.)"[82]. The services and hardware might differ, but the drivers and end user approach present clear connections.

Also the typical characteristics of P2P computing system can present some obvious relations:

- High degree of autonomy from central servers;
- Exploits resources at the edge of the network;
- Individual nodes have intermittent connectivity;

By applying peer-to-peer concepts to distributed generation and the electricity systems, users, or prosumers, could develop alternative ends for their excess generation exported to the grid, moving away from standard export remuneration regimes we have experienced in RE regulations until now. Also they could explore synergies with other users to make the most out of their production or storage systems. If sustainably established and regulated, P2P energy trading could portrait economic, social and environmental benefits. These are attained by leveraging the capabilities of end nodes (i.e. energy end-users), through incentivizing user cooperation to achieve a desired service, supporting dynamic self-reorganization and peer evolvement into interest communities, for instance RE diffusion.

The P2P energy trading concept seems to lead us to the following question, is the electricity grid being undervalued in its potential role for users?

Even though the term "peer" suggests one of equal standing with another, this is not necessarily accurate. P2P architectures can present more centralized or decentralized models, and also services of a more collaborative nature, or client orientated in the other hand, that seem to move away from philosophies such as the one defended by Dave Winer, software pioneer, “The ‘P‘ in P2P is People”[83]. Figure 24 shows us the usual taxonomy of P2P systems.

This disruptive concept for the energy sector is leading to the emergence of new actors that develop innovative business models in order to incorporate these ideas. We will look deeper into some of these examples through a selection of case studies further into this chapter.

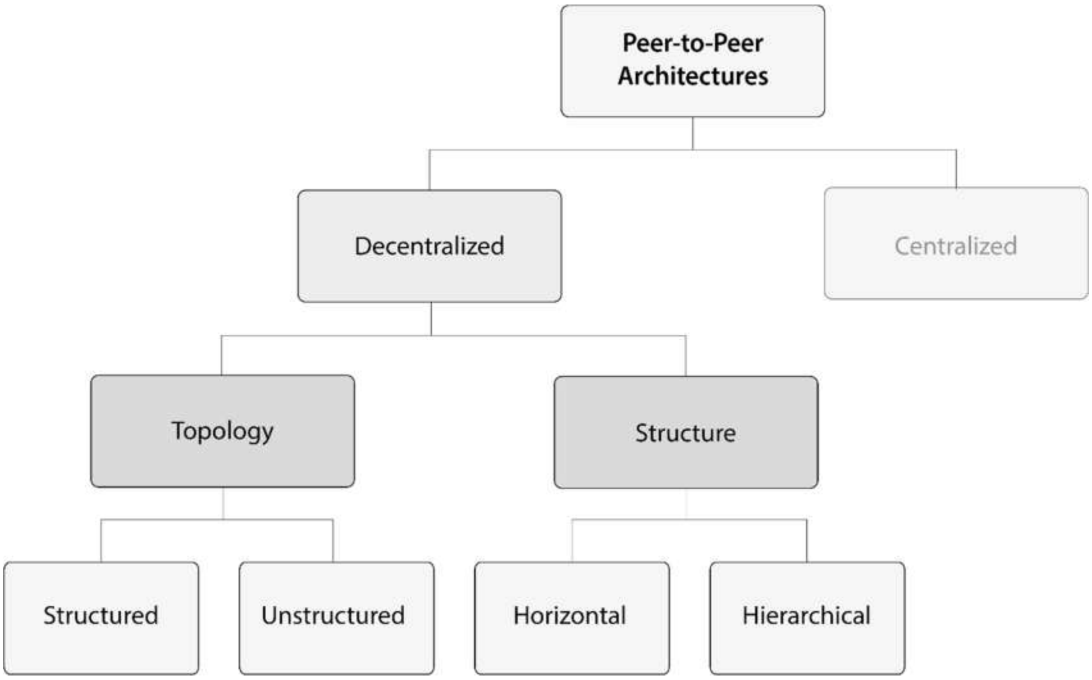


Figure 24 - A taxonomy of P2P systems (Source: adapted from VU et al. 2010)

5.1.4 Third part ownership

An important disclaimer should be made regarding third party ownership. Many regulations consider third party ownership, but in a standard system configuration where the RES is connected behind-the-meter or directly to the consumption point. This is different from the third party virtual metering concept that will be described in section 5.4.2, however it is also a fundamental aspect to enable particular business models within prosumer aggregation policies, since it allows for the emergence of “solar leasing” businesses and programs such as the one developed by SolarCity[84] or Yeloha (the Yeloha! case study, section 5.3.4).

Many third party initiatives and business models have proven particularly creative as they shift away from the customer-ownership model by building systems supported by customer lease or power purchase agreements (PPAs). Like a mortgage, lease agreements and PPAs allow system costs to be repaid by users over time, and require little or no money down. Customers can be cash-flow positive immediately, dramatically reducing the investment hurdle to go solar[13] . Third-party-owned projects now account for 57% of the market in California (**Erro! A origem da referência não foi encontrada.**) Similarly, in Colorado, the market share of residential customers leasing systems has grown to 57% in the 18 months since the state authorized leasing structures.

An NREL study of Los Angeles-area solar project data found that leased systems increased customer demand for residential PV systems by up to 28% from 2007 to 2011 in Los Angeles and Orange counties.

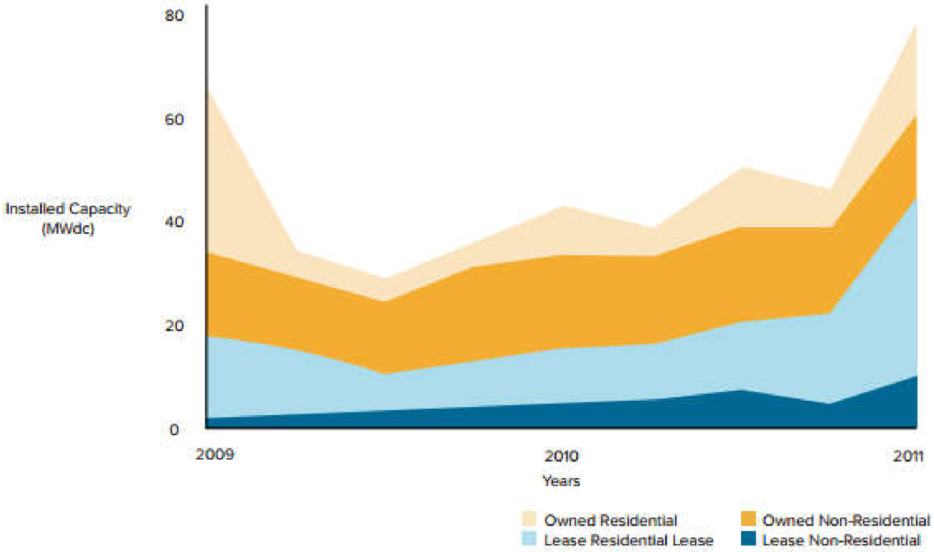


Figure 25 - Ownership of PV projects in California (2009-2011)

5.2 Motivations and potential benefits

By enacting this type of public policy mechanisms, regulators and decision makers can explore potential benefits in terms of the economical, technical and social aspect of self-consumption. These benefits can translate into increased policy diffusion, deployment rates, levels and quality. We chose six possibly attainable goals to summarize this potential, all subsidiaries to the startup questions, considered as policy enhancements opportunities and relevant for a more profound analysis:

1. Increasing the potential market available for self-consumption;
2. Minimizing energy exports through a smoother aggregated load curve;
3. Creating of alternative valorization mechanisms for excess generation;
4. Economies of scale opportunities and soft cost reduction;
5. Improve grid-connection quality and technical aspects of DG system;
6. The citizen initiative and peer power in accelerating diffusion

5.2.1 Increasing the potential market

It is frequently defended that these regulatory mechanisms could broaden the existing market potential for self-consumption, making it accessible even for those without the appropriate on-site conditions.

“Existing business models and regulatory environments have not been designed to provide access to a significant portion of potential PV system customers. As a result, the economic, environmental, and social benefits of distributed PV are not available to all consumers. Emerging business models for solar deployment have the potential to expand the solar market customer-base dramatically” [37].

Potential for distributed RE deployment can be assessed in different levels (see Figure 26), such as the resource potential, technical potential, economic potential and market potential. The effective market potential of renewable energy can be extensively influenced by policies and regulations, therefore presenting the pertinence of this topic.

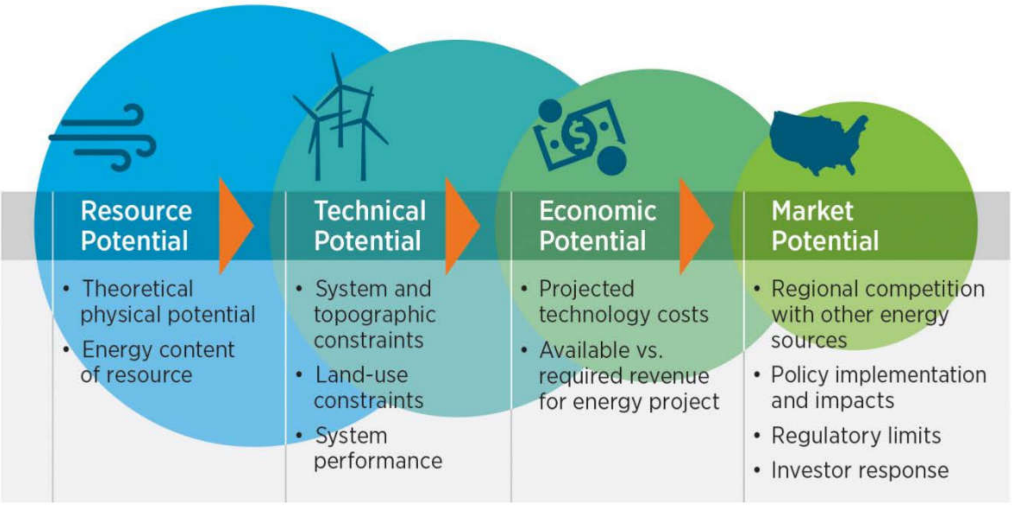


Figure 26 - Types of renewable energy potentials (Source: Brown et al. 2015)

There are numerous sites that cannot accommodate RE systems for diverse reasons, whose owners or renters could still want to either purchase energy exported by other prosumers, or build their own system in an off-site location, instead of “behind the meter” as typical self-consumption installations. Prosumer aggregation policies could therefore help minimize this loss of potential market, and additionally bring benefits to the economic and technical potential such as economies of scale (see 5.2.2) and peak shaving of surplus generation (see 5.2.3) respectively, which will further increase the overall potential.

Some of the most usual barriers to adoption that could be overcome by regulation are:

- Multi-house buildings
- Tenants on third party buildings
- Insufficient or inadequate roof space

- Unfavorable resource conditions

Blocking agents in these conditions can limit potential diffusion rates and cap the adoption curve to a level below the technically and economically feasible, restricting the market accessibility to a significant share of users. Estimating the self-consumption potential is not a trivial, in particular due to the complexity of roof top solar projections in terms of available roof area, the methodology to perform these assessments is not consensual but the most advanced models employ complex geographic information systems or three-dimensional models[85]. But even these can present several sensitivities to the assumptions used in the model, and might not take to consideration roof age, condition, and building material, which may prevent some buildings from installing PV [37], at least without an alternative mechanism that allows for off-site generation.

NREL conducted a research to evaluate solar rooftop technical potential in the USA across 128 cities covering 40% of the national population and 23% of the building stock, the results said that only 26% of the total rooftop area of small buildings is suitable for development, for medium buildings the suitable area is 49% suitable of the total rooftop area and 66% for large buildings[22].

These values will change according to the region's building profiles, population density, and other local specificities, however in most literature has consistently found that rooftop PV could supply 20% to 40% of total national electricity demand, and that a large percentage of this roof space is non-residential, this figures represent a clear motivation for off-site installations in order to allow access to all costumer types.

Another issue regards cities and multi-house buildings where retrofitting a RES and connecting it directly to each consumer installations might present several obstacles; additionally, multi-house buildings have a smaller roof area when compared with the whole inhabited area. However, in this case installation could still be either on-site, via policies such as tenant aggregation, or off-site via virtual metering.

In contemporary society, more than half the world's population lives in densely urban areas, with a tendency to increase this percentage, thus it is important to find alternative ways to approach this market segment. Policies could be properly designed and worded such that they provide fair and equal opportunities to all types of customers, provide easy access for customers, and easily administered by utilities.

Many barriers still exist for the majority of users that block the adoption of self-consumption RES, be it technical, financial, regulatory or even social. This presents a severe handicap for self-consumption deployment and potential, seeing that the majority of systems, particularly in the residential sector, are built solely in single family houses that only represent a small share of the housing market. The CEO of Yeloha! (one of the study cases reviewed in chapter 5.3) mentions that "Most people will not go solar, it's too complicated or expensive", he points out that today's solar market serves only a very narrow type of customer: those who have a home, don't plan to move soon, can afford to buy a system or have good-enough credit to lease one, and whose roofs are well-suited for solar.

5.2.2 Economies of scale and soft cost reduction

With the aggregation of prosumers in the generation side, the collective RES dimension will necessarily be superior to on a one-to-one basis, even when accounting with optimization effects in sizing. This can present economic benefits in the purchase of the systems' equipment, and also in terms of soft costs such a licensing, taxes and installation costs. Economies of scale are not restricted to large scale PV plants, it is very significant in micro scale PV systems as well. For instance, in the USA, 5-10 kW residential systems are currently 28% less expensive than systems of 2 kW and under on a $/watt basis [16], this remarkable difference is within small scale residential systems, if we increase scale to commercial, or utility size PV plants, the economic effects are even greater, as can be seen in Figure 27.

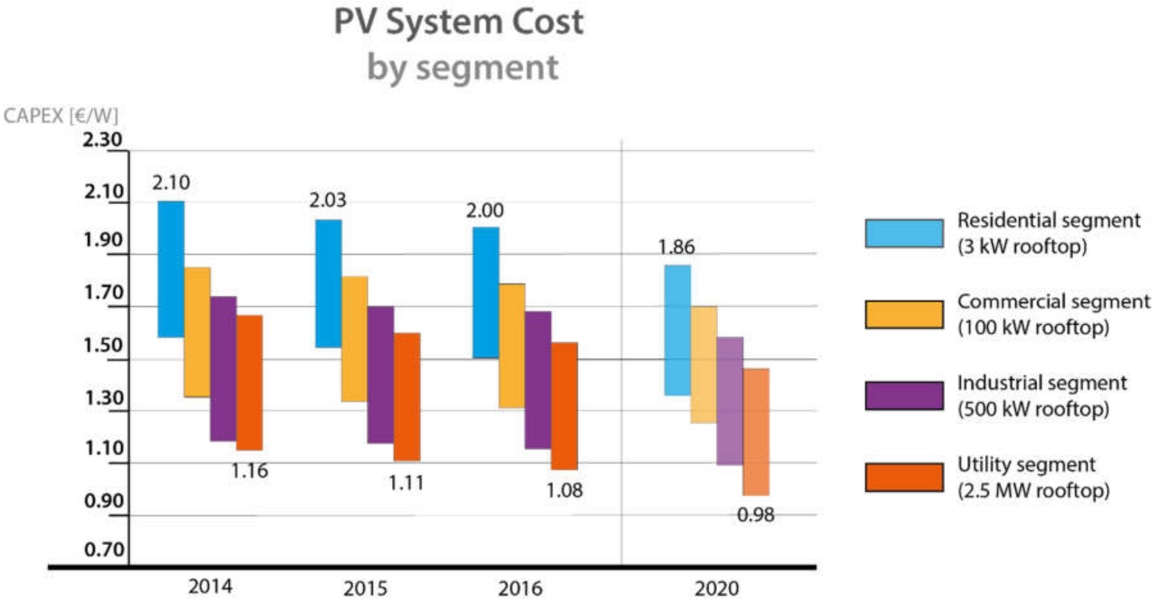


Figure 27 - Scenarios for future PV system prices evolution by system segment [€/W] (Source: adapted from EPIA 2012)

This economic advantage could present a social advantage allowing lower-income electricity consumers who own or rent affordable housing to self-consume PV electricity to cover part of their energy needs, therefore contributing to reduce the energy costs of families, positively affecting their disposable incomes. These models can also drive peer effects on adoption levels.

Economies of scale together with a higher degree of awareness due to a supporting community group could also portrait advantages in the adoption of additional equipment such as storage systems, energy managements systems or other initiatives such as demand side management that wouldn't usually occur in single entity systems.

On the business side for RE companies and utilities, shared generation can present advantages in terms of costumer acquisition costs, increased market opportunities, technically superior installations and also from the grid sustainability perspective, with collective off-site RES the location could be chosen in cooperation with utilities in order to provide optimal grid integration and system siting.

5.2.3 Increased load matching through a smoother aggregated load curve.

By removing the need for a spatial one-to-one mapping between distributed RE and the energy consumers who receive their electricity benefits, it is possible to obtain both technical and economic benefits[37].

A techno-economic issue is demand variability and its impact in load matching with non-dispatchable sources. Demand variability is an increased concern for prosumers in environments where export remuneration is valued under the retail rate, since the best economic profitability would derive from energy savings and not energy export. This is especially relevant in the residential sector, but not exclusive to, since residential consumption levels can go from residual demands when the building is empty (so called parasitic charges), to instantaneous demand peaks when there is use of certain high consumption appliances, that can have very short running periods.

By aggregating different demand profiles under the same RES, we can potentially achieve a smoother load curve from the sum of parts, guaranteeing a higher self-consumption ratio. The combination of heterogenic demand profiles is interesting since it can "fill the voids" of the aggregated load curve due to the mismatch of individual consumption patterns.

"The pooling of prosumers implied by lower load profile[12] volatility proved to be beneficial to self-consumption levels (up to 17.6%) in the modeled scenarios, hence suggesting that an efficient co-operation of prosumers can unlock further economic potential"[17].

Therefore, prosumer aggregation can present the following features to improve load matching:

- Heterogeneity among users' energy demand;
- A greater number of controllable energy consuming devices;
- Greater on-site energy generation capacity.

None of the above exclude prosumers from choosing whether to invest alone and share the excess, or collectively and share the whole benefits.

Another research on the topic considered a multi-house building with a shared system, and then a community of buildings with co-operative production and energy management. Comparing building and community levels, it can be seen that the net profiles[13] of the latter are smoother than the former [73]. This helps to validate that a higher combination of diverse demand profiles, produces a smoother average load curve. "Through energy sharing and DSM the aggregation of different sites allowed for an increase of the electrical demand covered by onsite electricity generation up to 21% (self-sufficiency ratio) and the on-site generation that is used by the building up to 15% (self-consumption ratio)"[73].

A further compelling question for this topic is how the overall demand profile smoothens through incrementing individual profiles. And what would the least number of aggregated users for this effect

---

[12] The demand profiles used had a 30min timestep

[13] The demand profiles simulated had a 1min timestep

to significantly occur. A research conducted to evaluate this issue where it is considered most relevant, the residential sector, analyzed a total of 27 different real residential demand profiles[14] and the consequences of their aggregation, through multiple combinations, on the overall demand profile and system performance. The study concluded that after the fifth house had been aggregated the excess electricity starts to stabilize, with a reduction from 10% to 25% on exports to the grid depending on system sizing criteria. However, the normalization of the overall profile and estimate error will continue to decrease with the addition of more individual profiles[86].

For the energy system on the other hand aggregation also depicts advantages when compared to individual systems, a greater level of load matching between distributed generation and consumption means a peak shaving effect on the exported energy, which can relieve some worries for grid operators in terms of predicting RE penetration and guaranteeing an end for that energy.

Summarizing, aggregating consumers can induce:

- Higher load matching, that leads to higher self-consumption ratios for promoters;
- Peak shaving effects, decrease exports to the grid;

5.2.4 Alternative valorization mechanism for surplus generation

Optimizing load matching through prosumer aggregation can bring additional economic advantages for prosumers, but does not completely avert excess generation and consequential export. Present storage technology costs are yet to be a standard viable solution, and even when under-sizing the system we still face the risk of export in high production peaks or due to demand volatility.

Therefore, searching for alternative valorization mechanism is an attractive idea, especially in frameworks where excess energy export is valued at lower rates than the retail electricity tariff. The lower this valuation is, the more natural it is for prosumers to find alternative ways to value that excess energy. “Virtual metering is the ability to ‘tag’ excess electricity produced by your solar panels and to assign that electricity to another entity. It means you don’t have to sell that electricity to the electric utility for a low price, but you can choose and directly sell to another grid connected user”[87].

By allowing prosumers to transfer or sell their surplus generation they might improve the economic performance of their system, or simply pursue a different behavioral driver or motivation, since prosumers could seemingly present also environmental or social motivations.

Additionally, it is the authors opinion that in places where market integration of RE is closer to reality and with the unbundling energy system agents, this liberalization should allow prosumers to become active participants of the market and be able to look for innovative ways to deal with excess energy export, as long as there is a market demand for it and a permitting regulation.

The approaches here researched and afore proposed are thereby compatible with the trends for market integration of renewable energies, without implying government incentives or cross-subsidies. It is

---

[14] The demand profiles used had a 15min timestep

argued here that prosumers do not need to resort solely to wholesale energy market pools to achieve this integration. This concept could open opportunities for new business models (see 5.2.1) that are currently constrained in regulations that establish a single standardized model to deal with surplus generation injected to the grid (such as the last resort retailer in the Portuguese law, a single retailer figure that acts as a aggregator/broker in the energy market).

Once more these alternatives could make use of peer to peer energy trading concepts, where a prosumer could contract his or her export to other consumers, to shared generation. Even though barely regulated, and often working around existing legislation, this idea has already led citizens and entrepreneur to develop new business models such as aggregators or market facilitators' platforms for joint investment or joint acquisition of production from multiple different prosumers. It is important to stress that these options do not necessarily clash with the liberalized market ideology, on the contrary, they can be seen expression of freedom for every energy user to participate in the energy markets, even if not the traditional market format. This could therefore present a democratic expansion of energy markets and its profits to include regular citizens as possible agents, while also opening a door for energy stakeholders of the tradition value chain to develop innovative costumer services and business models.

If one of the main goals of market liberalization has been to foster competition among generator, in fact prosumers activity increases competition in the electricity market. Prosumers can challenge incumbents' business models and add a greater number of players to the market, potentially many more than had been foreseen at the beginning of electricity market reforms[11].

Another issue of low remuneration for energy export, such as that of wholesale market integration, is reconciling them with increasingly exigent building codes such as zero energy building policies, or net-zero, which are gaining relevance across the globe. Zero energy building policies together with market integration trends fail to provide the economic drivers for developers to match yearly consumption to production, as this would lead high levels of grid export, which would at present technology cost heavily impact the return on investment, prosumer aggregation policies could be an alternative to address this problem.

The number one challenge to employing these often disregarded business models is purely regulatory, since frameworks typically do not create the legal provisions for its existence and development, and often even forbid it (Spanish and Portuguese case for instance clearly states 1 installation for 1 consumption point). The technical challenges of enacting such regulations could be surpassed through the digitalization of the grid and could create synergies with the roll out of smart meters.

Most of these models would induce the introduction of the virtual metering concept or virtual power plant, through dedicated regulations that could unblock on-site and off-site energy generation and sharing (Virtual Metering will be further discussed in chapter 5.3).

This idea is not as "fare fetched" as it can initially seem, since it presents clear analogies with how the traditional stakeholders of the energy value chain operate (in terms of grid usage and compensation, fungible resource, etc.). Since it also has similarities with the well know Power Purchase Agreement (PPA) in broad regulatory terms, typical in large scale power plants, the remarkable innovation would thus be the expansion of the actual stakeholders allowed to operate.

Usually DG generation does not fit the requirements for PPAs due to the smaller scales involved and uncontrollable energy dispatch. However, if we look to existing models of third party ownership under self-consumption we can find some examples of how to put this to practice. Additionally, with further policy diffusion, with the roll-out of smart meters, and by overcoming bureaucratic and management issues, this idea can become evermore evident for prosumers. Summarizing of the features achievable are:

- Compatible with market liberalization and energy system unbundling
- Increase market competitiveness with prosumer participation
- Standard export models constrain innovation and alternative valorization options
- Drivers for perusing energy trading can be economical, but also social or environmental ones

5.2.5 Improved system and interconnection quality

prosumer aggregation policies could not only present additional compelling drivers for prosumers, they can also present an opportunity for the energy system managers to improve DG system quality, interconnection quality, and support the digitalization of energy sector that goes in line with popular smart grid trends.

When compared to residential rooftop installations, the scale effect of aggregate generation can provide for better control on system equipment's, and overall quality. If off-site generation is allowed, there could be opportunities for the grid managers to locate the systems where they are deemed most useful for the system.

A shared system is also more likely to have better information technology equipment that increases DG visibility, such as dedicated telemetering, than in the case rooftop residential systems. This could help mitigate the grid operators worries surrounding variable RE forecasting. For both shared generation and P2P trading to occur, outside net-energy metering scenarios, there could be an increased need for smart metering in both the generation and consumption end, to evaluate load matching and set energy values, which also portrait benefits towards grid managers' supply security challenges.

Summarizing, some of the potential technical advantages of prosumer aggregation policies to the interconnection quality:

- DG location
- DG quality and regulatory control
- DG visibility
- Support the roll out of smart meters

5.2.6 Innovation opportunities

By establishing stable formal frameworks for prosumer aggregation, through public policy, programs and regulations, legally acknowledging the existence of this kind of generation systems, we create a favorable environment for the flourishing of innovation opportunities in the energy sector. It is argued in this work that such innovation opportunities could bring economical, technical, environmental and social benefits through the development of new business models and energy services.

Specific regulatory frameworks are not necessary to develop innovative business models, as can be seen by the case studies presented in the following chapter, i.e. in states without explicit virtual net-metering legislation or defined shared energy programs, utilities can still administer shared solar programs through their billing mechanisms[37]. However, the absence of regulation might limit activity permits, and handicap or even restrict innovation opportunities.

New ideas that explore concepts such as peer-to-peer energy trading and shared generation, through businesses or organizations, client or user orientated, are already emerging with a noticeable growth in the present decade. These new business models do not need to be directly connected to the energy transaction or energy generation, this also creates space for product developers to design equipment and software that is better adjusted to this reality, notice for instance the mission statement of Reposit Power, an Australian company specialized in storage systems, "The buying and selling of electricity has hitherto been the province of large or specialized companies such as electricity retailers. But Reposit Power says that homes and businesses can and should be able to trade electricity with the help of battery storage, and production facilities such as solar panels[88]".

The opportunity that shared solar represents to the traditional energy agents is less straightforward. While primarily developed to address customers' interest in self-consumption, these programs can also be leveraged to bundle other products and services, customer acquisition, grid optimization and compliance with renewable energy target, when such requirements exist, are two other ways that utilities can benefit. Retailers can be mandated to include certain share of RE generation in their energy mix (such as Renewable Portfolio Standards), through community solar programs to they may directly generate renewable energy credits or indirectly purchase them from prosumers [75]. Shared generation programs not only allow retailers to offer their customers a channel for buying RE directly, they can also provide a sales channel for other services. For example, the Minnesota-based co-op, Steele-Waseca Cooperative Electric (SWCE), is pioneering an innovative bundled service offering that benefits both the utility and its customers. As part of the SWCE community solar program[89], customers can opt to buy their portion of the shared solar facility at a discounted rate if they also install a new electric water heater in their home. The customer uses the excess power generated by their solar array during the day to heat their hot water heater, allowing them to avoid pulling that electricity from the grid during "peak load" in the early evening. This allows the customer to effectively "store" the excess solar power generated from their array. It also helps the utility to reduce peak demand (refer to chapter 4.4.2.3). Other products and services utilities might consider wrapping into their programs include appliance upgrades, efficiency retrofits, and compensation for participating in demand response programs[87]. Retailers may also see an opportunity in deploying self-consumption systems, and broker a virtual metering agreement, if it allows them to acquire and keep customers for longer term contracts, ensuring both the security of returns to the retailer and the generator’s return on investment. However, this incentive might be questionable in the case of costumers with a low demand, such as the residential cost, since it would require additional hardware, software and transactional costs to allow this service[87].

In terms of grid sustainability, utility-administered community solar programs allow the grid operator to make key decisions regarding the placement and design of the solar array, enabling them to optimize valuable power resources. For example, a utility might build the array with the panels facing west to boost output late in the day during periods of peak demand. This practice, commonly referred to as peak shaving, can reduce costs by avoiding deploying expensive peak energy to meet high demand. All consumers benefit from this approach, not only those who have invested in the array. Utilities may also choose to install tracking systems so that they can move the panels to align generation output with supply and demand. Additionally, strategically placed shared solar arrays might help utilities defer or avoid the cost of upgrading transmission and distribution assets by reducing their use and prolonging their useful life.

Other benefits can come from system placement on the grid, and in terms of system visibility and interconnection quality, developing synergies between different agents that would not occur in standard self-consumption configurations.

Regarding the energy grid’s financial stability, virtual metering or peer to peer trading has been advocated by many as one means where network operators could dodge the death spiral and grid defection scenarios. Rather than encouraging users to use battery storage to save the excess energy and perhaps go off-grid, allowing virtual metering means their poles and wires still have some relevance in the new energy architecture. These use of this poles could generate revenues through grid charges, applied at full value, or a discounted rate proportional to the degree of usage[39].

For the energy producer this is also a challenging concept, as increased DG will decrease overall energy demand. Capacity markets are foreseen as a way for traditional generators to maintain profitability, by offering back-up services for variable generation. Nonetheless for producers that chose to exploit the opportunities of these innovative concepts they could look to,

- Crowdfund investments’;
- Diversify generation assets;
- Lower capital risk of DG investments.

5.3 Business models and case studies

In this topic we will look into different models already put to practice by citizens and entrepreneurs, sometimes in partnership with conventional utilities. These recent initiatives can help gather knowledge from experience to let us understand trends, and also the challenges surrounding these concepts. Allowing for better policy and, particularly, regulatory design. These constitute a diverse set of case study models, chosen to display the multitude of ideas the energy system might have to face, or embrace. The examples are developed within distinct regulatory frameworks, which may or may not legally consider a prosumer aggregation mechanism, or even a self-consumption policy in certain cases. Nonetheless, with the appropriate provisions such as virtual metering and wheeling charge regulations present, these models could have solid ground to expand their presence.

5.3.1 SolarCondo

#Shared Generation

SolarCondo[90],[91]	
Promotor	CommunitySun®
Type	Limited Liability Company (LLC)
Goal	With a SolarCondo, anyone can generate their own solar energy. Many commercial utility customers have been excluded from owning their own solar power system due to cost, hassle or lack of access to a suitable rooftop, and the business models addresses this market.
Description (Summary)	Just like in a residential condo, a community of people each buy an individual SolarCondo within a solar facility, with shared interests in the land and common elements. The power from the entire solar facility enters the power grid, and through digital processes, the power generated by your SolarCondo is allocated to your residence and is credited on your utility bill. Each SolarCondo has a SolarDeed™ title that can be bought and resold.
Location	Texas (USA)
Date (roll out)	Reservations happening now for, work in progress with other Central Texas Utilities
Framework	Virtual net metering, Working together with utilities
Target	Any electricity consumer
Features (advantages)	No suitable location needed Allows to move consumption point Economies of scale Third party management Turnkey model and facilitated access Mortage rate financing available
Additional information	CommunitySun®, as Renewable Energy Developer, constructs SolarCondo® renewable energy systems that deliver affordable interests in utility-scale solar farms to individuals and businesses that cannot or do not want to install rooftop solar at their

	home or business. The utility-scale solar farm is organized under condominium law, CommunitySun is the developer and sells SolarCondos to business and residential customers. Similar to a traditional condominium, the renewable energy facility is supported by SolarOwnersAssociation® real-estate management services, and CommunitySun provides maintenance, operation and software services to the owners and the owners association. What's more, each SolarCondo system is bought and sold through SolarDeed™ brokerage services, just like other real-estate. **More cost-efficient:** **Compared with rooftop installations** – costs less and produces more energy than similar sized rooftop systems **Low up-front costs** – with mortgage-rate financing available **30% potential tax credit*** – from Uncle Sam **Long-term solar savings** – for 25 years or more

5.3.2 CleanEnergyCollective

#Shared Generation

Clean Energy Collective[92]	
Promotor	Clean Energy Collective
Type	Limited Liability Company (LLC)
Goal	Accelerate the adoption of long-term clean energy solutions - make them easier, cheaper, safer, and longer lasting. Provide utilities with lower risk, well located and more beneficial clean energy generation - smart clean energy growth Create a manageable and mutually beneficial production partnership between utilities and consumers
Description (Summary)	CEC is pioneering the model of delivering clean power-generation through medium-scale facilities that are collectively owned by participating utility customers. CEC's proprietary RemoteMeter™ system automatically calculates monthly credits for members and integrates with utilities' existing billing system.
Location	USA
Date (roll out)	2010
Projects	100 projects, 130 MW, 25 Utilities
Framework	Community-Owned Solar, energy is sold directly to the utility which then credits the generations profits on the costumers' utility bill
Target	Any electricity consumer
Features (advantages)	No suitable location needed Allows Tenants Economies of Scale Third party management Turnkey model and Facilitated access
Additional information	Utilities have agreed to buy this energy at a premium rate, paying you a certain percentage more than energy produced by a traditional, rooftop solar system.

5.3.3 SOM Energia

#Shared Generation

Generation kWh	
Promotor	SOM Energia
Type	Energy Cooperative
Goal	SOM Energia is a renewable energy cooperative, with a non-profit business model. Their man activities are energy generation and retailing. SOM Energia aims at transforming the actual energetic model to a 100% renewable energy system.
Description (Summary)	**Generation:** Energy is produced in shared RE power plants made possible by the members crowdfunded investment, the energy profits are then divided by the investers with an interest rate. **Retailing:** SOM Energia is an official retailer that manages and bills the members' electricity, allowing any consumer to purchase green energy.
Location	Spain
Date (roll out)	2015
Framework	Energy is sold through a PPA under the self-consumption regime. All of the retailed energy by SOM Energia is verified through guarantees of origin.
Target	Any electricity consumer
Features (advantages)	RE access for all Allows Tenants Non-profit organization Economies of Scale Third party management Turnkey model and Facilitated access
Additional information	The generation projects traditionally were made through bulk export FiT. However, with regulatory changes to self-consumption and the end of renewable subsidies, SOM Energia adapted its business model to utilize market integrated PPA's and their role as an separate energy retailer (Generation kWh project). The energy from the shared generation system is sold to SOM Energia costumers at cost of production, which includes maintenance and operational costs, generation tax (Spanish "sun tax") and a linear amortization of the project over 25 years. The predicted price is between 0,035 and 0,038€/kWh, which is approximately one cent below wholesale market price.

5.3.4 Yeloha!

#P2P energy trading

Yeloha![93][94]	
Promotor	Yeloha!
Type	Limited Liability Company (LLC)
Goal	Unblock solar access both to: -potential hosts without the credit for investment; -potential users without the appropriate location.
Description (Summary)	The company acts as a liaison between people who have solar-friendly roofs and people who want to buy the energy those roofs generate For the consumers, Yeloha's service works in this way. A homeowner whose roof is well-suited for solar energy receives a solar system free. As the solar system starts generating energy, the host sees a reduction on his or her utility bill. The host receives credit for about 25% to 30% of the energy produced and pays nothing. Yeloha allows other interested consumers, such as apartment owners and others for whom owning solar systems isn't a good idea, to pay for a portion of the solar energy generated by the host's solar system. The subscribers get a reduction on their utility bills
Location	Massachusetts; USA
Date (roll out)	The service was in Beta testing mode and failed to launch on the market
Framework	Virtual net metering scheme (Massachussets) credits excess to other users, Solar hosts and those that pay for the solar energy must be within the same utility. The company created a separate limited-liability company that will pay for and own the solar systems that are installed on hosts' roofs.
Target	Any electricity consumer **Sun Host -** In exchange for hosting, receives free solar panels and a portion of the energy they generate - at no charge. The rest of the energy is shared with my Sun Partners. **Sun Partner -** With solar sharing, I no longer need my own roof to go solar. No matter where I live, I can finally go solar by purchasing cleaner, cheaper energy on someone else's roof.
Features (advantages)	No suitable location needed No buy-in model possible Economies of Scale Third party management Turnkey model and facilitated access
Additional information	The host receives credit for about 25% to 30% of the energy produced and pays nothing. Yeloha doesn't care about a homeowner's credit score, since the homeowner doesn't have to pay anything to Yeloha. – Very interesting for social benefit in energy poverty - For Sun Hosts, there's no lease agreement, no commitment, and no credit check to sign up and get solar panels installed. "Most people will not go solar, it's too complicated or expensive," said Mr. Rosner (Yeloha! CEO), who believes that today's solar market serves only a very narrow type

	of customer: those who have a home, don't plan to move soon, can afford to buy a system or have good-enough credit to lease one, and whose roofs are well-suited for solar. "We found that 92% of the households in the country cannot go solar," Rosner told***Energy Business***. "No matter their motivations, they just can't do it. Either they don't have the right roof or they don't have the right credit. "From a business perspective, there's a huge opportunity in making it so everyone can connect to solar," Rosner says. Rosner could not divulge specifics on exactly how many homes are currently using Yeloha — although he was willing to say that he'd been overwhelmed by the "tremendous" outpouring of public interest. "We're using the infrastructure, so we need to find a way to work together with the utility companies," Rosner said, explaining that his company's plan has naturally raised hackles with some utility companies. "We see ourselves as a digital network on top of the existing infrastructure. We understand why the utilities are concerned about how their business models could be adversely affected. But we've also found that utilities are embracing change." Rosner found an uphill battle with some states that prohibit third party purchase (TPP) agreements. Those states have laws designed to protect utility monopolies by making it illegal for anyone who is *not* a utility to generate electricity and sell it to someone other than the utility company. The business ended up not launching to the mass markets, the announcement can be read underneath: "Over a year has passed since we first lit up our Solar Sharing Network. We're honored to have made solar energy a reality for many. We feel fortunate to have had the opportunity to reinvent the old grid model, and to prove the potential of a digital, two-way exchange that invites all of us to produce, consume and share our own affordable clean energy. Thank you, our Sun Partners, for being the first who subscribed online to buy solar energy produced on someone else's roof. Thank you, our Sun Hosts, for contributing your roof space for producing more energy than you could use. Unfortunately, the resources required to sustain Yeloha and bring it to the next level were not available in this environment. We had to shut down Yeloha, but we remain confident that solar sharing will shape the future of energy. Our users and supporters can take pride as pioneers on that journey."

5.3.1 SonnenBatterie

#P2P energy trading

SonnenCommunity[95][96][97]	
Promotor	SonnenBatterie
Type	Limited Liability Company (LLC)
Goal	The goal is to build a P2P Energy Trading Community, or network, of solar+storage owners that exchange and trading energy.
Description (Summary)	The sonnenCommunity is a community of sonnenBatterie owners who are committed to a cleaner and fairer energy future. As a member you can share your self-produced energy with other members of the sonnenCommunity. Since you are exclusively using renewable energy, there is no need for a conventional energy provider anymore.
Location	Pilot project in Berlin; Germany
Date (roll out)	2016
Framework	Sonnen registered as an official Retailer (SonnenEnergy), deploy sonnenbatteries for peak shaving and DSM, the members sell and buy electricity between the community, in case more energy is needed than the community produces they buy extra energy needs from RE producers. They also make use of the SC net-FiT scheme available.
Target	Any electricity consumer there are 3 types of members: Consumers, Prosumers and Producers.
Features (advantages)	Alternative surplus valorization 100% RE scheme Use of smart Storage systems Digitalization of the Grid
Additional information	Sonnenbatterie's goal is to build a virtual pool of owners of PV arrays and solar systems. Surplus electricity generated by PV and not utilized by home or business owners will initially divided among the members, and if not needed, will be traded on the wholesale market, Schröder explains" In addition, Sonnenbatteries intends to charge the batteries when wholesale electricity prices are in negative territory, to provide to the "community". This will allow members to save value added tax (VAT). For new participants to the program Sonnenbatterie plans to offer a discount on its battery system of €2,000 (US2,116). Given this, and a monthly fee of €19.99 per month, a LCOE of €0.23/kWh (US$0.24/kWh) is anticipated. This is competitive with retail rates in Germany. Sonnenbatterie is also employing new software that can visualize the aggregated storage in real time. The company envisages eventually integrating heating services onto the platform. A second phase of the project could incorporate rental properties, which are more common in Germany than in Anglo-Saxon cultures, in which pooled renewable energy could be provided. However, Sonnenbatterie imagines that limitations on this may have to be placed. "We want to ensure that the sources of supply remain authentic and the customers receive green electricity that really is regionally produced," Schröder added.

	Sonnen states that surplus electricity which can’t be consumed or stored can be shared online via the sonnenCommunity. Excess electricity is then made available to members who need power. The company adds this user bonus: With the favorable purchase price of a battery storage device, members with a sonnenBatterie also have additional advantages — they can direct-market their surplus electricity with an additional profit to the feed-in-tariff and pay a price significantly below the average of traditional suppliers for electricity they don’t produce themselves. Sounds like an intriguing clean energy bartering platform. Rebranding Takes Place With This Platform As part of this new business model, Sonnenbatterie GmbH will be renamed sonnen GmbH. sonnen will serve as the umbrella brand for its intelligent battery storage system sonnenBatterie and its networked electricity community sonnenCommunity. At its core, the sonnenCommunity will feature three technologies: decentralized power generation, battery storage technology, and digital networking supported with a self-learning software platform.

5.3.2 Piclo

#P2P energy trading

Piclo[40]	
Promotor	OpenUtility
Type	Limited Liability Company (LLC)
Goal	Create an online marketplace for renewable energy. The service gives consumers and generators direct access to each other, offering innovators a new model for buying and selling energy.
Description (Summary)	Piclo is the UK's only online marketplace for renewable energy. The service gives consumers and generators direct access to each other, offering innovators a new model for buying and selling energy. For sustainable businesses, Piclo is a tool to make conscious and active decisions about their source of electricity. For renewable energy generators, Piclo shows their electricity market and provides data visualisations and analytics.
Location	6-month pilot project in UK, with 37 consumers and generators.
Date (roll out)	2015
Framework	Ofgen granted permitions for Piclo to develop its 6-month pilot project .Piclo, Open Utility's software, takes in all preference information and matches electricity demand and supply every half hour - 48 times every day. Good Energy, an official Retailer, helps ensure that the marketplace is always balanced, purchasing surplus power or providing 100% renewable top-up when required.
Target	Commercial consumers and RE generators
Features (advantages)	Price control for producers Online market 100% RE scheme Decreased Grid Charges (TUoS) Choose your generator Know the supply chain Local generation Digitalization of the Grid
Additional information	Consumers pay distribution use of system charges to cover the distribution network operator's costs for the delivery of electricity to them. Based on a time-of-use calculation for half-hourly metered import customers, the charges are split into red, amber and green time periods. The red peak time can account for up to 93% of the total distribution use of system charges costs, even though it only covers a fraction of the time, a couple of hours per weekday. User feedback gathered during the trial suggested that most consumers didn't make decisions based on technology type, but according to their distance from the generators.

5.4 Virtual metering

During the international assessment on prosumer aggregation policies, several policy instruments, with similar or distinct formats were identified, such as aggregate metering, tenant aggregation, virtual net metering, remote metering, local energy trading, shared generation or community solar gardens. The bulk of these policies present a high degree of experimentalism, thus the lack of terminology consensus or best practice analysis.

It is important to stress that all the prosumer aggregation policies identified during the assessment resort to a particular self-consumption typology, which is self-consumption with net-energy metering. This means that all frameworks were developed in a context where surplus energy exports are valued at retail rates. Net-energy metering has been the most successful environment for the development of aggregation policies, within the self-consumption policy spectrum. It is also seemingly the reason why the common terminology found in literature is named virtual net-metering. In this work we chose to alternatively use the terminology virtual metering, to avoid implying that there is a netting of consumption and production over longer periods, similar to that of net-energy metering. The virtual metering approach explored throughout this work is developed to be adaptable to any format of self-consumption policy.

5.4.1 Definitions

In most cases, self-consumption laws require that the system is located on the customer's side of the meter and be sized so that it does not produce more electricity than is needed to meet on-site demand over the course of a year [33]. Alternatively, in situations where the system might not be located "behind the meter" or even on-site, this energy transfer is made through a regulatory mechanism called virtual metering (VM), amongst other nomenclatures. The name virtual metering is comprehensible as there is a virtual transfer of energy, and the benefits of this energy won't be seen in the regular consumption installation meter as energy savings, but credited to its users in a billing arrangement, through software or smart meters that enable this function.

> In the virtual net-metering format, it is said that it "enables the allocation of benefits from an electricity-generating source that is not directly connected to a customer's meter"[37]. Or the correlation and offsetting of the consumption by an RES that is not located the same delivery point where this consumption takes place[98]

These regulations allow for many different system configurations, thus definitions sometimes present slight changes, notice for instance the following:

> Virtual net metering allows the excess production from the solar array of one building to be credited against the consumption of another building[99] or virtual net-metering refers to when an electricity customer with on-site generation is allowed to assign their 'exported' electricity generation to other site/s. The other site/s may be owned by the generator or other electricity customers. The term 'virtual' is used to describe this sort of metering arrangement

> as the exported electricity generation is not physically transferred to the consumer, but rather transferred for billing reconciliation purposes.

Here the RES belongs to one entity (it could be located behind the meter) and uses excess generation to offset another entities needs. This is an example of the peer-to-peer energy trade concept.

But it could also be the case of an RES that does not belong to any single entity, but is collectively owned to offsets multiple that entities consumption, such as the shared generation concept. The system can alternatively be owned by an organization or third party.

> "The broadest expansion is virtual net metering, is that through which customers with multiple, noncontiguous accounts produce energy at one location and have that energy offset consumption at multiple other locations"[43].

The Australian pilot test rolled out in 2015 in five locations uses its own terminology for virtual metering, in the Australian test it was named local energy trading (LET) and defined as:

> "An arrangement whereby generation at one site is "netted off" at another site on a time-of-use basis, so that site 1 can 'sell' or transfer generation to nearby site 2. The exported electricity is sold or assigned to another site for billing purposes"[39].

For the purpose of this work, we propose virtual metering definition that is both broad, including both peer-to-peer energy trading and shared generation, and not restricted to net-energy metering frameworks, the definition proposition was worded as follows:

> Virtual metering is a regulatory instrument, through which a generation system(s) may allocate the benefits of the energy output, to consumption points not directly connected to the system.

5.4.2 Typologies of energy trading configurations

One of the advantages of the virtual metering concept here presented is that it can contain both shared generation and peer-to-peer energy trading schemes, enacted under the same regulation. Therefore, it does not restrict possible configurations, business models or future innovations, but rather include existing experiences of prosumer aggregation policies.

The characteristics of virtual metering regimes, as here classified, can present differences according to regulatory and political options, the definition proposed is intended to remain neutral to these aspects, allowing it to be ambivalent. Virtual metering specificities can vary in terms of:

- Allowed system location (off-site/on-site)
- System ownership
- Nº of entities evolved
- Energy trade configuration ('sold' or 'transferred', and value)
- Energy valuation
- Grid compensation tariffs

- Generation technology allowed

It can also present different configurations regarding production and consumption points:

- One to One
- One to Many
- Many to One

In Figure 1 we present different possible typologies of virtual metering, in terms of entities involved and energy transfer configuration. Four typologies were identified based on the suggestions of the Australian Institute for Sustainable Futures, aggregating a generation system and consumption points of a single entity, a third party, a community group or a multiple party platform. Within these four categories, or hybrid models, we are capable of classifying all the projects identified of prosumer aggregation policies. An important notice should be made to the fact that all of these typologies could be developed in on-site or off-site conditions if a proper regulation is established.

We will now look closely into each of these project types and capabilities.

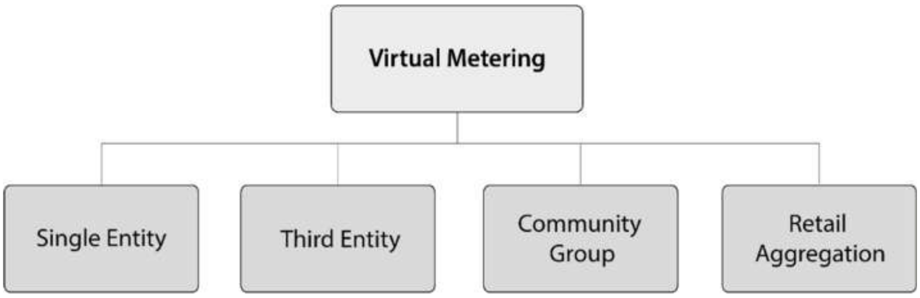


Figure 1 - Virtual Metering Typologies

- **Single entity**: In this type of virtual metering, there is only one entity involved. Let us consider a homeowner that has several houses therefore several consumption meters. However not all of them have self-consumption systems installed and he or she might wish to transfer its excess energy to its other properties instead of receiving an export remuneration.

  This also makes sense for commercial, industrial, agricultural and public organizations that might have several meters under the same entity's management.

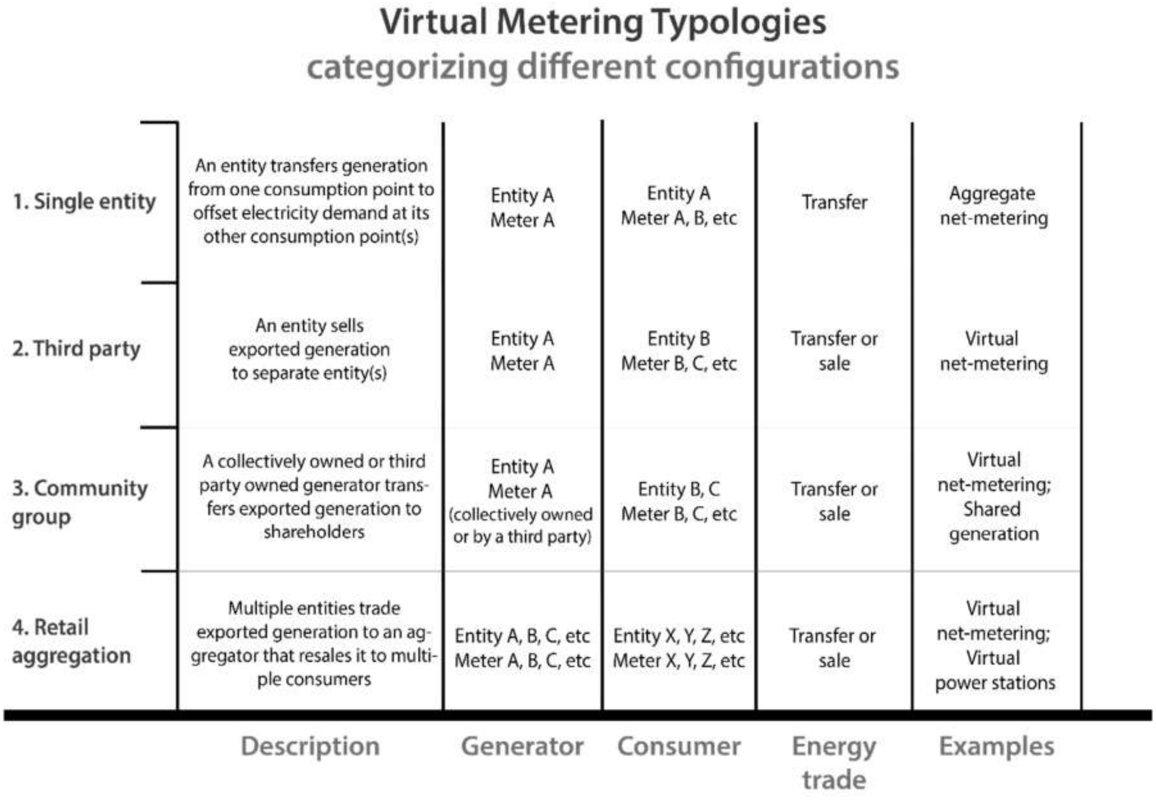
- **Third party**: In this type of virtual metering, the energy transfer is made between two different parties. Imagine for instance a self-consumption system owner who wishes to transfer his excessive energy to another consumer. A contract can be established so that the excess energy is traded to this third party (similar to the structure of a prosumer aggregation policy). This is different from third party ownership, popularized by solar leasing business models, where the consumer installation would serve as host for a self-consumption RES from another entity, and purchase the energy of that system for instance.

- **Community group**: In community group virtual metering the system is shared by a group of entities that distributes the collectively produced energy in a pre-arranged proportion. This can be useful in situations of unfavorable site and resource, or for sites where there is a need or advantage in sharing the installation such as multi-house buildings. Even though community might induce a neighborly sense of proximity, the term is meant to refer to a group of individuals with a shared interest.

RES cooperatives could particularly make use of this model, as multitenant buildings where direct “behind-the-meter” connection is technically constrained.

- **Retail aggregation**; In retail aggregation virtual metering, or multi-entity virtual metering, a network of prosumers trade their generation output to one entity. This central entity can then act as a market broker or redistribute it to multiple consumer entities, constituting a virtual power plant, or aggregate retailing platform.

Already some innovative business models have appeared using this kind of frameworks, from simple platforms that match producers with consumers, to disruptive new utility models. The following table organizes important characteristics and possible arrangements of different typologies of virtual metering.



Virtual Metering Typologies
categorizing different configurations

	Description	Generator	Consumer	Energy trade	Examples
1. Single entity	An entity transfers generation from one consumption point to offset electricity demand at its other consumption point(s)	Entity A Meter A	Entity A Meter A, B, etc	Transfer	Aggregate net-metering
2. Third party	An entity sells exported generation to separate entity(s)	Entity A Meter A	Entity B Meter B, C, etc	Transfer or sale	Virtual net-metering
3. Community group	A collectively owned or third party owned generator transfers exported generation to shareholders	Entity A Meter A (collectively owned or by a third party)	Entity B, C Meter B, C, etc	Transfer or sale	Virtual net-metering; Shared generation
4. Retail aggregation	Multiple entities trade exported generation to an aggregator that resales it to multiple consumers	Entity A, B, C, etc Meter A, B, C, etc	Entity X, Y, Z, etc Meter X, Y, Z, etc	Transfer or sale	Virtual net-metering; Virtual power stations

Table 6 - VM Typology characteristics (Source: Adapted from ISF 2013)

5.4.3 Off-site and on-site virtual metering

There are two types of virtual metering in terms of systems siting, i.e. the location of the generation system versus the location consumption point:

- On-site virtual metering, if the generation system is at the same location as the consumption point.
- Off-site virtual metering, were the generation system is located at another location.

How the on-site is defined is therefore import, it can be described as a physical distance between points or an irrelevant use of the grid to transport self-consumed energy, but it does not imply behind the meter configuration. While the concept might seem disruptive, it is in fact the *modus operandi* of the traditional energy system, since the electrons your energy supplier purchases for your consumption are not necessarily the same as those you consume. This is due to the fact that energy is fungible (electrons are indistinguishable whether generated on or off-site), therefore the virtual metering concept could theoretically be applied even for installations that are not in the proximity of the consumption point. Similar to energy purchased from the grid, virtual metering might assume that there is a need to compensate the grid for its usage.

It is important to keep in mind that with the unbundling of the energy system, the grid should be seen less as an asset of energy suppliers, and more as a public infrastructure that could be used by multiple agents upon fulfilling certain requirements, conducted under the management of the grid operator. The absence of appropriate regulations and transport charges can contain the emergence of prosumer aggregation policies. It is here argued that this is why net-energy metering has been so successful in the emergence of virtual net-metering policies, since grid cost and services and are usually not compensated by prosumers in net-energy metering. This creates a simple environment for the management of this energy transfer, being treated the same way as energy credits from surplus generation, this way without the need for any additional hardware or software we are able to transfer the associated production credits effortlessly through billing mechanisms.

Nonetheless, virtual metering regulations could also be developed in other self-consumption typologies, and assume an energy transport charge. Compensating grid usage for this energy transfer could be done simply through the application of standard grid charges (i.e. the same volumetric rates end user pay for grid-consumption) or through a dedicated charge. If both the generator and consumer in a virtual metering arrangement are located within the same local network area (e.g. distribution zone, distribution feeder line or geographic area), it is arguable that the final consumer of the electricity could be exempt from a proportion of the transmission use of system and distribution use-of-system charges. These cost reflective grid-charges are usually named wheeling charges, local network charges or local distribution charges, they will be fundamental for the economic performance and viability of the system. Figure 21 was designed to help us better understand this issue. Three scenarios are illustrated, in terms of grid charges, that can handicap or support the economic performance of the system:

- On-site generation, exempt from grid charges;
- Off-site generation, exempt from a proportion of grid charges;

- Off-site generation, requiring full compensation of grid charges.

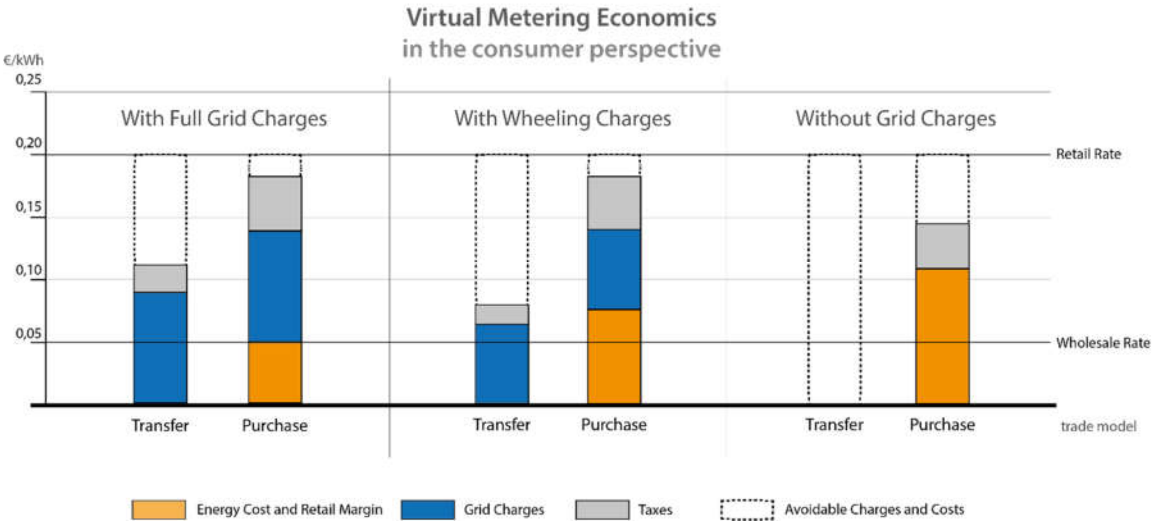


Figure 28 – Figurative economics of virtual metering from the consuming-end perspective, with variable grid charges (Source: Author)

For a virtual metering business model to be successful, it is likely that it has two minimum requirements:

- The final energy cost (i.e. including all components) should be lower than retail electricity rate, from the receiving end perspective;
- The energy component sale price (i.e. orange component) should be higher than the systems LCOE, from the generators perspective.

5.4.4 Regulatory vicissitudes

There are two main principals of standard self-consumption regimes, that are affected, or enhancements, by enacting virtual metering policies, these principles are:

1st - that one generation point is connected to only one consumption point;

2nd- that both points are located *in situ*, either behind-the-meter, or immediately after-it, before existing sub-meters.

These principles are explicit or implicit in most self-consumption regulations and definitions identified, not accounting for local context-related specificities[15].

In this topic, groundwork is developed in order to recreate what could potentially be required to allow virtual metering regulations. Several elements are considered such as the minimum information to be

---

[15] Swedish housing cooperatives for instance, no special provision is made in the self-consumption regulation but grid-connection schemes of housing cooperatives allow the use of a single multi-tenant meter[35].

made accessible, formalities and agreements that need to be set and legal regulatory provisions that should be undertook. This groundwork was compiled through the research review of literature and best practices, as well as the authors input and considerations. It provides insights to regulators, decision makers and the research community of what could constitute the predictable steps required to formally establish a prosumer aggregation policy.

5.4.4.1 Minimum data requirements on system and trade configuration

By allowing for variable number of participants, in either the generation or consumption side, we create several possible configurations:

- One to One
- One to Many
- Many to One

The configuration by which a virtual metering arrangement is set should be defined prior to any development. This should make clear through an agreement that contains:

- The typology of the arrangement
- The involved parts
- The respective service delivery points
- The respective contracted energy suppliers
- The respective functions and responsibilities

The documentation and information of the agreement should be made available to all contracting parts, but also to the system operators and energy suppliers involved.

In case of a shared generation system, additional information might be necessary such as:

- The ownership model
- The energy share model

How a customer is compensated for a share of electricity, the documentation of the agreement, and the marketing of the product may all influence the customer's motivation and perception [37].

5.4.4.2 System eligibility and costumer eligibility

System eligibility could be restricted to certain technologies, either based on resource (solar, wind, hydro), or type of resource (renewable, non-renewable).

Also costumer eligibility could be set to allow only a certain type of customers to access this program, examples were found of prosumer aggregation policies specific for the agricultural sector and public organizations (e.g. State of Maryland[100] and Virginia[101]).

5.4.4.3 Geographical proximity requirements for meters under on-site virtual metering

Virtual metering regulations might distinguish if the generation system is on-site or off-site, in this case it is important to clearly define what is considered the boundary limit of an on-site versus an off-site system. Off-site generation might also have distance limits established, a usual restriction is guaranteeing that all parts are under the same independent system operator load zone, or the same local distribution network, this is particularly important since interconnection between grids of different countries, states or even regions might be scarce or non-existent.

To be considered as on-site generation, virtual metering regulations can present distinct requirement or restrictions towards the geographical proximity of meters. For example, in more constrained versions of virtual metering, such as meter aggregation and tenant aggregation, the customer meters are required to be on a single property or contiguous properties, this means that if a customer owns several adjoining properties, meters on those properties can be aggregated. Many state rules allow meters to be aggregated across roads or other easements, that may cross through a customer's otherwise contiguous property. In on-site virtual metering it is important to make clear what is meant by the terminology chosen in terms of systems location, since whether or not aggregation is allowed for a continuous string of properties or properties intersected by roads (or other easements) depends on the state's definitions of "contiguous," "adjoining," "on-site" or "facility site". On the grids perspective, on-site could be expanded to any two points within the same feeder line, or the lowest transformation station level.

The typical methodologies for defining on-site generation are:

- Located on the same or contiguous properties;
- Located within a maximum distance;
- Located within the same substation level or service delivery point.

5.4.4.4 Grid compensation and wheeling charges for off-site virtual metering

If the virtual metering regulation allows for off-site systems regulators might choose to create a grid compensation mechanism, to partially or entirely refund grid usage. This is not the case in most virtual net-metering regulations identified, since as in standard net-energy metering scenarios the grid services are considered free of charge. "This is effectively 'free' use of the network, which may be acceptable for policy purposes, but is not cost-reflective as the network is still required by the distributed generator" [87].

Virtual metering should not be restricted to scenarios where the grid services are seen as a free service, since the payment of grid services such as energy transfer can be seen as technically fair, and could be built on a cost reflective basis.

The Australian pilot on local energy trading seems to cleverly identify this issue, studying the implication of various grid charge scenarios, one where full grid charges are required (like any other kWh that flows through the grid), and two additional scenarios that introduce the concept of local network charges calculated with different parameters. Local network charges are reduced network tariffs for electricity generation used within a defined local network area. This recognizes that the generator is using only part of the electricity network and may reduce the network charge according to the calculated long-term benefit to the network. A local network charge, that discounts the positive contributions of DG, can still help grid operators address the following issues:

- Inequitable network charges levied on a generator/consumer pair;
- Dis-incentivize duplication of infrastructure (through private wires) set up to avoid network charges altogether;
- Maintain use of the electricity network and grid financing.

A more common terminology for similar frameworks are the so called wheeling charges. Wheeling electricity is the process of transmitting electricity from a producer to a user in the same balancing area or from one area to another. This mechanism has historically been used by traditional producers, more recent examples of wheeling charge regulations can be found in countries such as the USA, Mexico or India[102], usually it is only accessible for large scale producers or industrial consumers. However, as an increasing amount of variable renewable generation is accessible for citizens and businesses, existing wheeling charges are a precedent for the energy trading concept, that could expand to regular consumers. Policymakers and regulators are adopting new or revised wheeling transmission and distribution charges that could effectively support renewable development[102].

The methodology by which local network charges ought to be set is still unconsensual, in fact it presents an important field for future research since it can raise a number of questions on the variables, or impacts to account, and how to model and quantify these costs. Two overall approaches were identified in the literature:

- A network-based would be most appropriate for calculating accurate wheeling charges based in the real cost of use; rates can present several levels according to the extent of the usage, for example, users on the same feeder line or within the same zone substation region as the generator are eligible to pay the lowest wheeling charge[87].
- A geographic-based definition may be easiest for participants to engage with; for example, to be eligible to pay the lowest wheeling charge, the consumer would need to be located in the same postcode or local government area as the generator, or separated by a maximum radial distance[87].

5.4.4.5 Customer quantity and other participation limitations in shared generation virtual metering

Costumer quantity requirements or participation limits are an example of typical regulatory options for shared generation projects. For virtual net-metering schemes, many USA states set a minimum or maximum number of customers that can participate in a shared generation project. In addition, a state might require,

- a minimum capacity for each subscriber;
- limit the percentage share a customer can own;
- limit the ownership capacity in relation to the customer's own electric consumption[33].

For example, both Colorado and Minnesota limit each individual customer to a 40% share in the system. Colorado requires that each customer must own at least 1 kW of capacity, and Minnesota requires each customer own at least 200 watts[33].

5.4.4.6 The role of the grid operator

To enable virtual metering, energy metering data of both generator and consumer must be reconciled by the grid operators through billing mechanisms, ideally instantaneously or on an interval basis (i.e. quarter-hourly) to assure load matching. Doing so requires both generator and consumer to have digital interval meters with a short time step, telemetering functions might also be useful. As part of a virtual metering arrangement, the grid operator (or retailers) may take on the role of:

- Ensuring that billing systems in place to reconcile the meters of the consumer(s);
- Calculating then applying an appropriate wheeling charge (if wheeling charges are part of the VM arrangement).

The system operator may also be required to inform retailers of network boundaries which align with the virtual metering administrator's definition of 'local' to enable retailers to determine the locational eligibility of participants. Nonetheless this challenge brought by prosumer aggregation policies goes in line with the smart grid concept, often envisioned by society, and "digitalization of the grid" trends.

5.4.4.7 The role of energy retailers

An increasing number of energy retailers are looking into including energy trading and shared generation in their business models. The minimum functions of the retailer with respect to virtual metering would be:

- To test participant eligibility based on location and customer type;
- To broker the agreement between the generator(s) and the consumer(s) if required;
- To ensure billing systems in place to reconcile the meters of the consumer(s) (this may alternatively be undertaken by the system operator).

Existing retailers may have a private incentive to broker a virtual metering agreement, particularly if it allows them to acquire and keep customers (both generators and consumers) for long term contracts, ensuring both the security of returns to the retailer and the generator's return on investment.

5.4.5 Challenges

5.4.5.1 Setting fair grid charges

The use of the transmission and distribution system for the consumption of electricity is generally charged to consumers through a standard grid tariff levels for different consumer profiles. It can be separated into the transmission use of system and distribution use-of-system charges, or a similar local variation of the terminology, and could present fixed and variable consumers. The common procedure for collecting these tariffs is for them to be settled on the end user electricity bill, by the energy retailer, and the funds are then transferred to the respective grid operators.

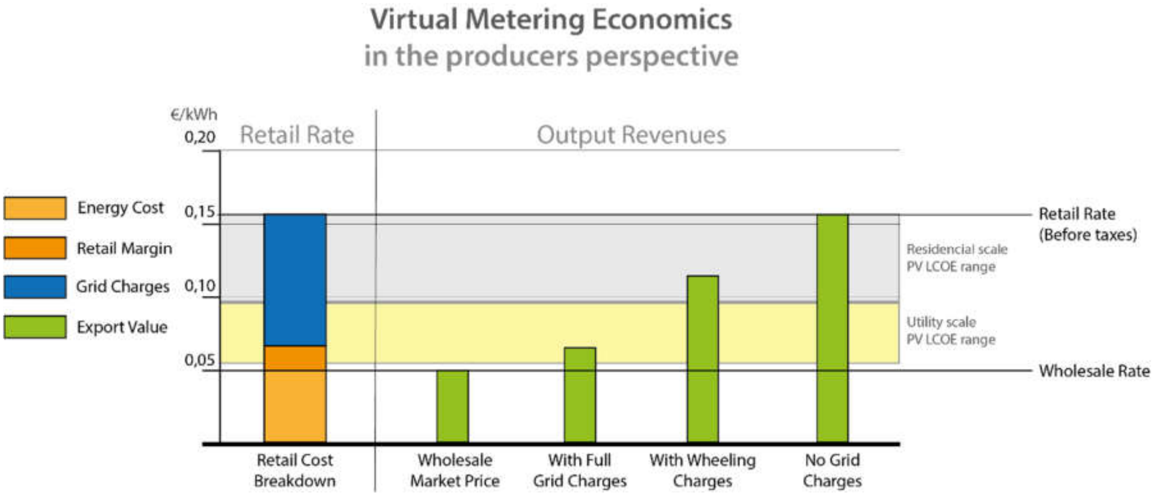


Figure 29 -Figurative economics of virtual metering from the producer's perspective, with variable grid charges (Source: Author)

Nonetheless this is not the exclusive model, or regulatory instrument, for the execution of grid-financing charges. Local network use charges and wheeling charge mechanisms have also historically been present in many jurisdictions, on a smaller basis. Empirically these mechanisms were applied to allow high demand consumers (i.e. industrial consumers) in regimes of power purchase agreements or similar, in order to avoid the payment of full grid charges or the creation of a dedicated private line, generally this was supported by a proximity benefit argument. Generally small scale DG generation, such as residential prosumers, is not allowed participation in these mechanisms.

Regulating grid charges for off-site virtual metering is a necessary step and could unlock further market opportunities for self-consumption. These charges could be set through the maintenance of the standard full charges, or by calculating dedicated charges. These dedicated charges (Wheeling charge or local network charges) can account for the avoided costs created by DG systems, such as the avoided transmission cost. While standard grid charges might constrain market opportunities particularly to the residential, these avoided cot discounts could on the other hand serve as an incentive for prosumer aggregation policy models.

This is a disruptive concept for traditional energy system principles, but one that goes in line with system unbundling and market integration. It represents an important step in the transformation of the energy sector and concerns all the stakeholders involved, some with questionable interest in such changes, and be subject to political good will and regulation redaction timeframes.

5.4.5.2 Interconnection visibility

The change of the one to one restriction adds costs and complexity. Certain potentially crucial data on interconnections might be required on a systematic basis, such as:

- Consumption delivery point;
- Production delivery point;
- Respective Zone Substation code;
- Metering of output and input in a short timestep[16];

The formal data of the interconnection point can sometimes not be easily accessible, and complicate permit attribution processes. This data is also fundamental in case local network charges are enacted, for they will be a likely requirement for their calculation.

On another side, for virtual metering off-site generation to be compatible with self-consumption, with the exception of net-energy metering, the regulation is more likely to demand that consumption and production meters are able to verify instantaneous supply-demand load matching to confirm that self-consumption conditions are present, and attribute an energy value for billing purposes. This could therefore require an upgrade of existing meters, and clarifying who would be accountable for such upgrades.

5.4.5.3 Digitalizing the electricity sector

Prosumer aggregation policies inherently increase the number of active agents participating in markets or making use of the grid infrastructure. To allow for this expansion to small scale generators to occur sustainably from the grid operator's perspective, it is likely that regulatory standards need to be developed and improved. The roll out of information and communication technologies such as smart meters, are a predictable step to assure load matching, and appropriate grid charging.

The challenges brought by these necessities ought to be used to increase accessible data on the whole system, and forecast on prosumer generation, strategically developing them to mitigate possible negative impacts.

---

[16] To comply with self-consumption, the timestep should be lower than 15 min.

5.4.5.4 Securities issues

Shared generation can raise a concern around the financial aspect of group investment, depending on national conditions and frameworks. This is due to the uncertainty about the applicability of financial security regulations, and requirements for registration and disclosure of projects details. Central to this issue is whether an interest in a shared solar project is a standard for profit investment, constituting a "security". If it is, then it is usually regulated by its own regulatory entity, and subsequently specific requirements and taxation. CommunitySun, LLC (refer to section 5.3.1,) is an example of a business model that successfully defended that the participation in a shared solar project should not be considered an investment contract, and may not otherwise be considered a security. They argued that participants' primary motivation for participating in the shared solar project is personal consumption (i.e., reducing a prosumer's retail electricity bills), not the expectation of profit, and the terms of participation include certain provisions to prevent the use of the agreement as a financial play. In such cases, a small payment to a shared solar program participant for excess generation exported to the grid may not lead to classification as a security as long as electricity consumption remains the primary goal of the program[37].

The same happens with the cooperative movement, one of the reasons for choosing a cooperative business format is that can it be used as a workaround to allow for these crowdfunded group investments.

5.4.5.5 Traditional energy system agents

The biggest challenge for energy retailers to incorporate virtual metering are the thin margins in the market. Even for single entity virtual metering, retailers face additional software, hardware/metering and transactional costs associated with reconciling virtually linked meters at a quarter-hour interval basis, or less. While it is expected that such costs would diminish with scale, there is both an initial set up and ongoing reconciliation cost burden, the Australian experience defends that while not insurmountable, this poses challenges to developing commercial activity in an area where margins are thin, requiring larger energy loads to ensure a return. As such, there is a clear barrier to retailer participation in brokering virtual metering agreements particularly between smaller generators and consumers.

Options to overcome this could include:

1. Mandating or incentivizing retailer participation through a policy instrument;
2. Creating a "second-tier" type of retailer which would facilitate the transfer or sale of electricity within a certain local proximity,

This "second tier" type of retailer would likely step in to facilitate virtual metering agreements which existing retailers do not see as profitable (due to transaction costs), by citizen or business initiative, through profit and non-profit organizations. For such entities to appear they should be governed by a less-stringent set of market rules with lower barriers to entry. For example, a 'community retailer' may set up to aggregate local distributed generation and sell it locally, or to broker individual virtual metering arrangement between local generators and consumers which are too small to interest existing retailers[75]. UK's retailing license lite regulation is an example of such policy provisions, license lite is an option that helps new suppliers enter the electricity supply market, for this to occur, the new supplier must have made a commercial arrangement with a third party licensed supplier before the grant of a license lite direction. Under this arrangement, the third party licensed supplier carries out compliance for those parts of a supply license that may be particularly challenging for a new supplier (which are often relatively small organizations).

5.5 Conclusions on prosumer aggregation

The same way self-consumption could be seen as a citizen right for any electricity user, energy trading and cooperation within citizens could portrait an additional natural right of prosumers, assuming appropriate regulations and compensation for the use of the infrastructure are in place.

If we look to the transformations enacted by prosumer aggregation policies on regular self-consumption policies (or in other policy genres), there is one seemingly evident outcome, an increase of prosumer potential market. When compared with standard self-consumption policies, both positive and negative impacts are mostly attributed to an increase of deployment rates, and subsequent increase of the DG penetration share. Therefore, there is no additional challenge for the energy system that was not already caused by increasing levels of non-dispatchable distributed generation, although prosumer aggregation policies might require some specific infrastructure improvements, namely in terms of metering equipment and billing systems.

A precedent for such frameworks can in fact be seen in power purchase agreement contracts between large scale consumers and energy producers, that bear significant resemblances to the virtual metering concept, and are already enacted in numerous countries. These power purchase agreements can also be considered as an off-site self-consumption model since:

- It grants the right of self-consumption, since electricity is bough and valued accounting for load matching;
- Grid usage is compensated, sometimes through *ad hoc* charges;

Although these agreements already exist, for instance Google in 2016 announced that it had bought the output from two wind farms in northern Europe[103], they are yet to be accessible to the vast majority of energy users. If there are no strategic grid related constrains to increase renewable energy shares, there should be no barriers to support and develop prosumer aggregation policies and regulations, seeing that they can catalyze diffusion and enhance technical, economic and behavioral drivers for self-consumption, also allowing a more equitable and democratic access to the mechanism.

Prosumer aggregation can also have advantages for retailers and grid operators when compared to traditional one to one self-consumption systems, mostly related to interconnection sitting, quality, and visibility, but also to customer acquisition and the diversification of revenue streams. Notwithstanding challenges of revenue erosions are a likely outcome due to the increase of self-use.

For grid operators however, off-site virtual metering grid charges can maintain grid usage and financing, paying a cost reflective rate, and avoid grid-defection scenarios.

Figure 31 in annex I summarizes the potential benefits attained through prosumer aggregation policies, which were discussed throughout this chapter.

5.5.1 Energy trading needs wheeling charges

Wheeling charges, or local network charge are fundamental to allow off-site virtual metering to occurs, without either underfinancing the energy grid, by applying no charges, or overcharging grid usage, by applying standard full charges.

These two concepts, energy trading and wheeling charge, are independent but complementary, with different effects on a consumer's energy bills, as illustrated in Figure 30. In most cases, the wheeling charge will reduce the network charge portion of electricity bills, while energy trading may reduce the combined energy and retail portion.

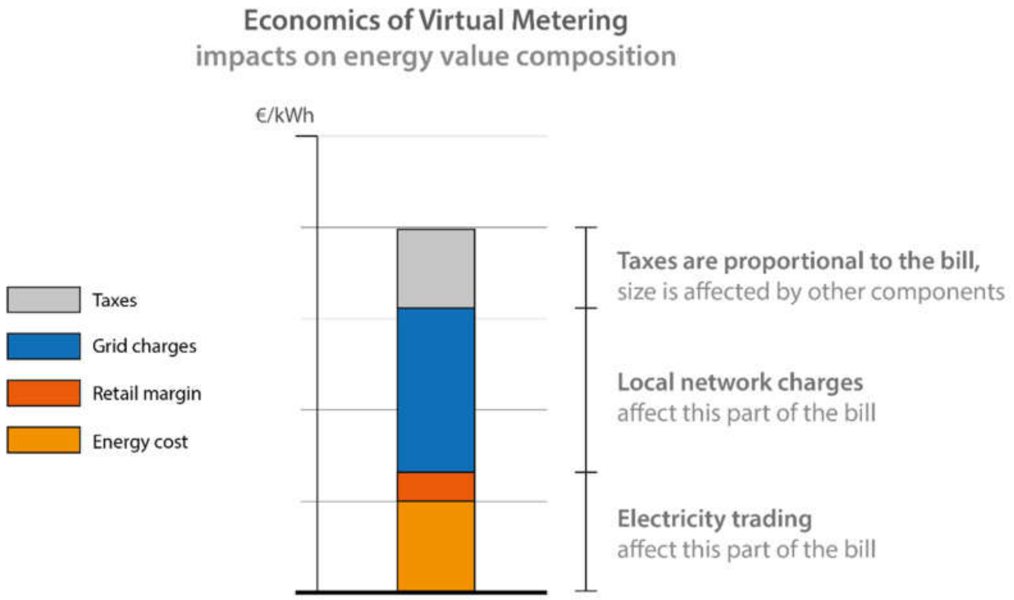


Figure 30 - Impacts of virtual metering in the composition of purchased energy value (Source: Author)

This is without doubt an innovative step for the energy system, but one that goes in line with its major trends. Market liberalization should not stop in the traditional supply chain comfort zone, rather it should allow and simplify the participation of any willing citizen that complies with stipulated necessary regulation.

5.5.2 Lessons from experience

From the international survey on exist prosumer aggregation mechanisms, and the case studies reviewed, it is possible to draw some conclusions. While on one hand they point the challenges and weaknesses of the concept, they also serve as a proof of concept for the opportunities it presents, in the diversification of the energy markets actor, allowing for innovation and competition.

The proof of concept is evident, as these models already exist successfully in the absence of specific regulation (e.g. Sonnebatterie, SOM Energia). Nonetheless the absence of regulation can be a heavy constrain in rolling out these models, raising issues such as,

- the appropriate model to crowdfund shared generations systems, avoiding the classification as a security (discussed in section 4.4.5.4);
- how to manage this energy trade and what network compensation is mandated;
- what entities are allowed to manage these models;

These constrains can leave many ideas and innovations in the drawing board, even if they seemingly generate public interest (e.g. Yeloha!).

Enacting these regulations can provide a more suitable framework to foster these new business opportunities, but not only for traditional energy agents. Equipment manufacturers, beyond generation technologies, are calling out for these regulations, such is the case of the initially battery manufacturers Sonnenbatterie that created an virtual energy trading platform and registered as an energy retailer, or metering and billing software developers such as OpenUtility with the Piclo product that tested out a similar pilot project. They also have been used by social or environmental models, such as the SOM energia energy cooperative, that was able to successfully develop an off-site shared generation project in PV, in pure market conditions, and paying full grid charges as an normal energy retailers.

5.5.3 Steps for developing prosumer aggregation policies

In order to develop prosumer aggregation policies decision makers and regulators should consider the following points, in order to facilitate the emergence of new business models within defined frameworks and guaranteeing grid sustainability.

1. Regulate remote self-consumption; both for single entity or multi-entity (energy trdin)
2. Distinguishing on-site and off-site scenarios;
3. Regulate local network charges, or wheeling charges, for off-site configurations;
4. Establish the “shared generation” figure, enabling a legal path for collective ownership and investment that is safe from securities issues.
5. Regulate third party ownership of self-consumption systems;
6. Establish the “aggregator” or “market facilitator” figure, a limited retailing license with a less-stringent set of market rules, lowering market participation barriers;

While other aspects might be considered, these points are hereby argued as the necessary steps to enable *ad hoc* provisions for all the frameworks and business models surveyed throughout this research.

Chapter 6 - Conclusion

6.1 Considerations and proposals

“Self-consumption remains the way to go: the only business model for PV in the future outside of utility-scale plants selling their electricity is and will remain self-consumption – PV as a way to decentralize electricity production and to reduce electricity bills”[56].

If cost reductions estimates for RE are correct, self-consumption is a likely scenario for the future of the energy system. The international assessment and literature review allowed us to see this is a growing theme in energy policy, and even though production purposed renewable power plants will continue to exist, in both subsidized and integrated in market full export conditions, on the other side we will have consumers who find self-consumption more affordable than grid-consumption, turning into prosumers. Self-consumption can therefore be seen both as a transition policy in the phasing out of incentives, but also as a mature policy capable of existing in market integrated scenarios.

This work set out to make a concept analysis of self-consumption and prosumer aggregation policies, this revealed to be a complex and multidisciplinary analysis. Macro and micro modeling of the scenarios discussed would have usefully complemented this research, but the scale of a master’s dissertation project did not allow for both paths to be pursued effectively. Therefore, the first step would necessarily be a comprehensive holistic overview of self-consumption, were the main topics that surround self-consumption where addressed and the existing literature and examples discusses. This can serve as groundwork necessary for a researches which set out to model self-consumption or prosumer aggregation scenarios.
Summarized next are some of the initial conclusions attained in this research on the self-consumption policy genre.

- Self-consumption is a natural behavior as long as an appropriate cost effective solution exists, it can emerge even in the absence of regulation (chapter 1).
- Policy labelling is yet to be stabilized, and different terminologies are implied across borders (chapter 2);
- Benefits for policy analysis and experience exchange can be achieved through the use of clear terminology, such as the one proposed in this work’s terminological concept analysis (chapter 2);
- The share of the self-consumption policy genre has increased significantly in the present decade, and indicates an upwards trend (chapter 3).

As an emerging concept for the energy sector, and since it makes use of distributed generation, it is understandable that questions are raised about the implications of the behavior. The impact for the energy system brought by self-consumption policies is a complex question, including numerous stakeholders and outcomes, nonetheless two separate issues ought to be acknowledge:

1. **The impact of surplus export remuneration;** this political option can influence the economic sustainability of the energy system and self-consumption economic attractiveness;

2. **The impact of distributed generation on the grid;** this is the technical challenge and benefit brought by distributed generation in general, and self-consumption policies in particular.

The first can have widely different approaches on the regulatory level that will incur different outcomes, from market integration that dismisses the impact, to highly incentivized policies which can stress final electricity costs for consumers. Through the assessment it is possible to notice that stakeholder's pressure to increase standard grid charges, or prosumers dedicated charges, is superior in the frameworks with higher incentives, such as net-energy metering or high feed-in tariffs. On the other hand, the impact of distributed generation on the grid (i.e. the actual technical impact and net-cost to the grid) is a separate issue, that can present both benefits and constrains. The net effect of these impacts is not consensual as it will depend on the variables accounted, the penetration levels and technologies involved, nonetheless it is often referred to as neutral, or even positive in the overall picture.

Summarizing the conclusions on impacts:

- The energy system economic performance is more affected by export remuneration policies, rather than the impact of distributed generation;
- The technical challenges of self-consumption are related to grid-injection and ramping power;
- Load matching is still limited, particularly in the residential sector, therefore self-consumption ratios are hampered without optimization strategies or under-sizing the system.
- Self-consumption can present economic and technical advantages when compared to full export policies by decreasing energy purchase expenditures (through subsidies for instance) and adjusting system size to match demand (chapter 4.2);
- The impacts of self-consumption are not an obstacle for deployment at present and medium-term penetration levels (chapter 4).

On the other hand, summarizing the mitigation strategies for these impacts:

- Grid operators will need to adapt rate design to the transformations of the demand profile, the trend is to increase the decoupling of revenues from energy volume.
- Demand profile transformation trends are not brought solely by self-consumption, therefore dedicated prosumer grid charges ought to be avoided, particularly in non-subsidized scenarios;
- Exposing surplus generation to market signals can mitigate several negative impacts of self-consumption (chapter 4.3);
- Similarly optimizing the self-consumption ratio, or promoting load matching, also presents benefits for the grid, and can be driven by decreasing export remuneration policies.
- Storage solutions still require further developments to improve cost effectiveness for the mass market, total self-sufficiency is estimated to be cost competitive in over 15 years (2030 to 2050, chapter 4 section 4.4.3.4).
- Storage solutions can be beneficial for the grid operator, as they can provide grid services such as peak shaving, but will aggravate retailers' revenue erosion.
- Prosumer aggregation polices can be developed to mitigate traditional impacts, through improved system siting, quality and visibility.

- Local network charges can help postpone a grid defection scenario with storage reduction costs, avoiding a utility "death spiral".

Traditional self-consumption policies have a limited potential market, numerous factors such as appropriate site conditions, ownership rights on the property, available credit for initial investment, can heavily decrease deployment opportunities. One particular market niche that self-consumption has been poorly adapted to is multi-house buildings, which represent an growing share of housing. Prosumer aggregation policies are hereby defended as a way to improve the potential market and enhance prosumers' drivers, while also addressing challenges of grid integration and market integration of distributed generation. Prosumer aggregation policies make use of virtual metering regulations (or similar) to allow for energy trading and shared generation, they could be seen as another step towards the full unbundling of the energy system,

- market integration does not stop at the energy market pools, and bilateral or multilateral contracts should be expanded to smaller scale consumers.
- the use of the grid infrastructure for energy transport ought to be expanded new agents, other than energy retailers.

Precedents for these behaviors already exist for large scale consumers, and they could portrait benefits for the grid by developing new revenue streams for its financing, avoiding grid defection and decreasing non-chargeable self-sufficiency. Therefore, the increasing rollout of prosumer aggregation policy could be seen as beneficial to all sides.

- *Ad hoc* regulation is not necessarily needed, many business models can find ways to work within existing regulatory frameworks, nonetheless specific policy action can support innovation (chapter 5.3);
- Energy trading and shared generation are natural subsequential paths after granting the right to self-consume;
- Access to wheeling charges, or local network charges, help to fully enable virtual metering, these could go from conservative standard full grid-charges, to cost/usage based discounted charges;
- Local government can have a strong influence in changing rules and regulations to allow for meter aggregation;

6.2 Future research

Due to the recent emergence of self-consumption regimes, and the novelty of virtual metering applications in distributed generation, several field of studies are still open for further research, which could solidify knowledge around the policy genre and support up-to-date literature. Macro scale modeling of these changes to energy systems, and quantifying its outcomes, is necessary to enable and anticipate regulatory challenges. Discussion around the impacts of self-consumption and distributed generation is still frequent, surplus remuneration and grid compensation mechanisms are also far from stabilized, which might point to the need to maintain a continuous analysis on policy developments, such as the work being developed by the North Carolina Clean Energy Technology center for the net-energy metering context[32].

For the self-consumption policy theme, further research is needed in topics such as:

- Assessing the diffusion rates in self-consumption regimes;
- Quantifying the impacts of self-consumption for different stakeholders, particularly the energy system value chain and tax collectors;
- Develop best practices on the methodologies to quantify these impacts;
- Evaluate the impact of the load profile timestep in the modeling of self-consumption surplus generation;

This last aspect is particularly important, while performing techno-economic analysis of self-consumption systems the majority of researches reviewed did not use real data nor model in a timestep that verifies real load matching, this can create discrepancies between theory and experience. The maximum timestep used in such analysis should be 15 min.

The prosumer aggregations policy theme is even less explored than its counterpart, providing an opportunity for much work to be developed. Evaluate the advantages of these systems when compared to regular self-consumption, strategies for using distributed generation and prosumer aggregation policies for grid-services require techno-economic studies to analyze and quantify several aspects such as:

- Load matching improvements through prosumer aggregation;
- Potential market expansion;
- Economies of scale opportunities;
- The impact of different formats of energy transfer network charge (e.g. no charge, wheeling charge rates, and full rates), particularly on economic viability, for the residential, commercial and industrial customer type;
- Modeling the impact of wheeling charges in grid financing;
- The grid-service potential;

References

[1] REN21, *Renewables 2015 global status report*. 2015.

[2] REN21, “Global Status Report - Renewables 2016,” 2016.

[3] R. Schleicher-Tappeser, “How renewables will change electricity markets in the next five years,” *Energy Policy*, vol. 48, pp. 64–75, 2012.

[4] REN21, “10 Years of Renewable Energy Progress,” pp. 2004–2014, 2014.

[5] I. PVPS, *Trends 2015 in Photovoltaic Applications*. 2015.

[6] WWF, “15 Signals for energy transition,” 2016.

[7] Greenpeace, GWEC, and SolarPowerEurope, “Energy [r]evolution,” 2015.

[8] M. Metayer, C. Breyer, and H. Fell, “The projections for the future and quality in the past of the World Energy Outlook for solar PV and other renewable energy technologies.”

[9] M.-L. Bemelmans-Videc, R. Rist, and E. Vedung, *Carrots, Sticks & Sermons: Policy Insturments & Their Evaluation*. 1998.

[10] European Comission, “Guidelines on Environmental and Energy State Aid for 2014-2020,” pp. 1–24, 2014.

[11] IEA-RETD, “Residential Prosumers - Drivers and Policy Options (RE-Prosumers),” vol. 2014, no. September, pp. 1–123, 2014.

[12] J. Mühlenhoff, “A wecome culture for consumers’ solar self-generation policy - Policy recommendations,” 2016.

[13] RMI, “Net energy metering, zero net energy and the distributed energy resource future,” 2012.

[14] H. Gouzerh, S. Orlandi, N. Gourvitch, and G. Masson, “Quantitative analysis of the Merit Order Effect from photovoltaic production,” pp. 3894–3900, 2013.

[15] NREL, “The Next Generation of Renewable Electricity Policy How Rapid Change Is Breaking Down Conventional Policy Categories,” 2015.

[16] International Energy Agency, “Tracking Clean Energy Progress 2013,” *Technology*, pp. 1–82, 2012.

[17] P. Kästel and B. Gilroy-scott, “Economics of pooling small local electricity,” *Renew. Sustain. Energy Rev.*, vol. 51, pp. 718–729, 2015.

[18] G. Masson, J. I. Briano, and M. J. Baez, “Review and Analysis of PV Self-Consumption Policies, report no. T1-28:2016,” 2016.

[19] T. Huld, N. Taylor, A. Jager-Waldau, and S. Szabó, “Cost Maps for Unsubsidised Photovoltaic,” no. SEPTEMBER, 2014.

[20] I. Gaëtan *et al.*, “PV DEVELOPMENT AS PROSUMERS : THE ROLE AND CHALLENGES ASSOCIATED TO PRODUCING AND SELF-CONSUMING PV ELECTRICITY,” 2014.

[21] T. Lang, D. Ammann, and B. Girod, “Profitability in absence of subsidies : A techno-

economic analysis of rooftop photovoltaic self-consumption in residential and commercial buildings," *Renew. Energy*, vol. 87, pp. 77–87, 2016.

[22] NREL, "Rooftop Solar Photovoltaic Technical Potential in the United States - A Detailed Assessment," no. January, 2016.

[23] M. Latour, "Net-metering and self-consumption schemes in Europe," no. September, 2013.

[24] European Commission, "Best practices on Renewable Energy Self-consumption," 2015.

[25] J. Dehler, "Self-consumption of electricity from renewable sources," no. June, 2015.

[26] D. Rendschmidt and A. T. K. Berlin, "Enabling the european consumer to generate power for self-consumption," no. November, 2011.

[27] J. A. Toledo and V. Cassagne, "Self Consumption of PV Electricity," 2013.

[28] G. C. Christoforidis *et al.*, "A Model for the Assessment of Different Net-Metering Policies," no. April, 2016.

[29] N. R. Darghouth, R. Wiser, G. Barbose, and A. Mills, "Net Metering and Market Feedback Loops - Exploring the Impact of Retail Rate Design on Distributed PV Deployment," 2015.

[30] D. Electric and D. For, "Net energy metering, zero net energy and the distributed energy resource future."

[31] F. Flores-espino, "Compensation for Distributed Solar : A Survey of Options to Preserve Stakeholder Value Compensation for Distributed Solar : A Survey of Options to Preserve Stakeholder Value," 2015.

[32] North Carolina Clean Energy Technology Center and Meister Consultants Group, "The 50 States of Solar: 2015 Policy Review and Q4 Quarterly Report," 2016.

[33] C. Barnes, "Aggregate Net Metering : Opportunities for Local Governments," no. July, 2013.

[34] M. Bolinger, "Community Wind Power Ownership Schemes in Europe and their Relevance to the United States," no. May, 2001.

[35] N. Sommerfeldt and Henry Muyingo, "Lessons in community owned PV from Swedish multi-family housing cooperatives," 2016.

[36] Open Utility, "A glimpse into the future of Britain ' s energy economy," 2016.

[37] NREL, "Shared Solar - Current Landscape , Market Potential , and the Impact of Federal Securities Regulation," no. April, 2015.

[38] J. Farrell, "Beyond Sharing - How Communities Can Take Ownership of Renewable Report," no. April, 2016.

[39] J. Rutovitz, E. Langham, S. Teske, A. Atherton, and L. McIntosh, "Virtual trials of local network charges and local electricity trading: Summary Report," no. May 2016, 2016.

[40] Piclo, "Piclo FAQs," 2016. .

[41] SolarPower Europe, "Renewable Self-Consumption - Cheap and Clean Power at your Doorstep Key messages," no. June, 2015.

[42] North Carolina Clean Energy Technology Center, "DSIRE - Nevada net-energy metering policy," 2016. .

[43] P. Curran and G. W. Clarke, “Review of Net Metering Practices,” no. December, 2012.

[44] North Carolina Clean Energy Technology Center, “DSIRE - Mississippi net-energy metering policy,” 2016. .

[45] L. Javier and K. W. Steininger, “Photovoltaic self-consumption regulation in Spain: profitability analysis and alternative regulation schemes,” no. October, 2015.

[46] P. Pennance, “Definition according to Aristotle,” pp. 1–3, 2014.

[47] Economic Consulting Associates and Carbon Africa, “Assessment of a net metering programme in Kenya - Volume 1 Main report,” vol. 1, no. March, 2014.

[48] W. Rickerson, J. Koo, J. Crowe, and T. Couture, “IEA RETD - Commercial Prosumers – Development and Policy Options,” no. March, 2016.

[49] Energy Matters, “Feed-in tariff for grid-connected solar power systems,” 2016. .

[50] J. Farrell, “Minnesota ’ s Value of Solar,” no. April 2014.

[51] Department of Energy & Climate Change, “Review of the Feed-in Tariffs Scheme,” no. December, 2015.

[52] K. Schneider, “Recent Facts about Photovoltaics in Germany,” 2015.

[53] XIX Governo Constitucional, *Decreto de Lei 153/2014 - Autoconsumo de Energia*. 2014, pp. 5298–5311.

[54] I. TSAGAS, “Israel’s Parliament installs rooftop PV, applies net-metering innovation,” *PV magazine*, 2014. .

[55] North Carolina Clean Energy Technology Center, “DSIRE - New Mexico net-energy metering policy,” 2016. .

[56] G. Masson, “Reviving the stalled shift to solar self-consumption,” *PV Tech Power Volume 6*, 2016. .

[57] G. Wynn and G. Reid, “In Sight : Unsubsidised UK Solar.”

[58] Delloit, “Unlocking the value of community solar Utilities find opportunity in the inevitable growth of distributed energy resources for Energy Solutions Contents,” 2016.

[59] NREL, “Value of Solar : Program Design and Implementation Considerations,” no. March, 2015.

[60] L. Hirth, “The Market Value of Variable Renewables : The Effect of Solar and Wind Power Variability on their Relative Price The Market Value of Variable Renewables,” 2013.

[61] J. Z. Rokach and I. Introduction, “Net Metering Needs a Safety Net,” pp. 106–108, 2011.

[62] C. Eid, J. Reneses, P. Frías, and R. Hakvoort, “The impact of Net-Metering on Cross Subsidies between Network Users,” pp. 1–10, 2013.

[63] Advanced energy economy and MIT, “21st century electricity system CEO forum summary,” 2013.

[64] F. Sioshansi, *Distributed Generation and its Implications for the Utility Industry*. 2014.

[65] A. Brown and J. Bunyan, “Valuation of Distributed Solar : A Qualitative View,” *Electr. J.*,

vol. 27, no. 10, pp. 27–48, 2014.

[66] NREL, "Distributed Solar PV for electricity system resiliency - Policy and Regulatory considerations," pp. 1–12, 2014.

[67] J. Lazar *et al.*, "Teaching the ' Duck ' to Fly," no. January, 2014.

[68] I. California, "What the duck curve tells us about managing a green grid," pp. 1–4, 2016.

[69] G. Bolton, "People in Germany are now being paid to consume electricity," *Independent*, 2016. .

[70] F. R. Spellman, *Environmental Impacts of Renewable Energy*. 2014.

[71] IEA PVPS, "Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems," 2015.

[72] IPCC, "Renewable Energy Sources and Climate Change Mitigation," 2011.

[73] R. Amaral, J. Martins, D. Aelenei, and C. Pantoja, "A cooperative net zero energy community to improve load matching," vol. 93, 2016.

[74] M. R. Jongerden, "Reduced Grid Capacity Impact by Self Consumption of Photovoltaic Energy," pp. 1–8.

[75] Center for Sustainable Energy, California Solar Energy Industries Association, and Interstate Renewable Energy Council, "Virtual Net Metering Policy Background and Tariff Summary Report," pp. 1–66, 2015.

[76] ANEEL, "Entram em vigor novas regras para geração distribuída," *Ambiente Energia*, 2016. .

[77] The State of Colorado, *House bill 10-1342 - Concerning measures to encourage additional investment in solar energy generation facilities, and, in connection therewith, authorizing the creation of solar gardens.*, no. 10. pp. 1–11.

[78] IRENA and GWEC, "30 Years of Policies for Wind Energy: Lessons from 12 Wind Energy Markets," pp. 54–63, 2011.

[79] REScoop, "European Federation for Renewable Energy Cooperatives," 2016. .

[80] E. Funkhouser, G. Blackburn, C. Magee, and V. Rai, "Energy Research & Social Science Business model innovations for deploying distributed generation : The emerging landscape of community solar in the U . S . 𝔊," *Chem. Phys. Lett.*, vol. 10, pp. 90–101, 2015.

[81] M. Hefeeda, "Peer-to-Peer Systems ∗," no. 1, pp. 1–16.

[82] Q. H. (et al. . Vu, "Architecture of Peer-to-Peer Systems," 2010.

[83] A. Oram, *Peer to Peer : Harnessing the Power of Disruptive Technologies*. 2001.

[84] "SolarCity," 2016. .

[85] J. Melius, R. Margolis, and S. Ong, "Estimating Rooftop Suitability for PV : A Review of Methods , Patents , and Validation Techniques Estimating Rooftop Suitability for PV : A Review of Methods , Patents , and Validation Techniques," no. December, 2013.

[86] I. Almeida, "Autoconsumo de Eletricidade Solar em Edifícios Residenciais Resumo," 2015.

[87] E. Langham, C. Cooper, and N. Ison, "Virtual net metering in Australia: Opportunities and Barriers," pp. 1–19, 2013.

[88] G. Parkinson, "Households to use solar + storage to trade electricity with grid," *Reneweconomy*, 2014. .

[89] F. Jossi, "Minnesota co-op combines community solar, efficiency," *Midwest Energy News*, 2015. .

[90] Pedernales Electric Cooperative, "PEC announces solar pilot programs at second hill country solar tour," *Power of community*, 2012. .

[91] CommunitySun, "SolarCondo renewable energy system," 2013. .

[92] CEC, "Clean Energy Collective," 2016. .

[93] Y. CHERNOVA, "Peer-to-Peer Solar Network Yeloha Gets $3.5 Million to Launch in U.S.," *The Wall Street Journal*, 2015. .

[94] S. Hanley, "Uber of Rooftop Solar? Yeloha?," *Clean Technica*, 2015. .

[95] PV magazine, "Interview with Sonnen USA CEO Boris Von Bormann," 2016. .

[96] S. ENKHARDT, "Sonnenbatterie launches solar+storage community platform," *PV magazine*, 2015. .

[97] G. Meyers, "Germany's Sonnenbatterie Launches Energy Trading Platform," *Clean Technica*, 2015. .

[98] Photovoltaic News, "Problems in the application of net-metering." .

[99] G. Parkinson, "Byron shire to be first in Australia to pilot virtual net metering," *Reneweconomy*, 2015. .

[100] North Carolina Clean Energy Technology Center, "DSIRE - Maryland net-energy metering policy," 2016. .

[101] North Carolina Clean Energy Technology Center, "DSIRE - Virginia net-energy metering policy," 2016. .

[102] J. Heeter, R. Vora, S. Mathur, N. Renewable, and P. Madrigal, "Wheeling and Banking Renewable Energy Wheeling and Banking Strategies for Optimal Renewable Energy Deployment : International Experiences," no. March, 2016.

[103] Reuters, "Google buys output from two new Nordic wind farms," 2016. .

Annex I

Figure 31 - Benefits of Prosumer Aggregation Policy (Source: Author)