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Alternative Fuel Adoption Behavior of Heavy-duty Vehicle Fleets in California: Insights Gained from In-depth Fleet Interviews

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Outline

1. Introduction
2. Initial Theoretical Framework Based on Literature Reviews
3. Qualitative Research Approach
4. Results: 12 Main Insights
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1 Introduction

Key Definitions

- **Heavy-duty vehicles**: medium and heavy-duty vehicles are defined by their gross vehicle weight rating, though it varies by agency, with the US Federal Highway Administration definition being vehicles over 10,000 lbs, while U.S. Environmental Protection Agency (EPA) sets the lower limit at 8,500 lbs.

  * GVWR: the maximum total safe weight a vehicle is designed to carry including the net weight of the vehicle with accessories, and the weight of passengers, fuels, and cargo.

- **A fleet of vehicles**: a group of one or more vehicles belonging to an organization for a business purpose rather than personal transportation use.

- **A fleet operator**: a person who owns and/or manages a fleet of vehicles and is solely or collaboratively involved in the process of fleet purchase decisions for that organization.

- **Alternative fuel vehicles**: vehicles running on cleaner fuels than traditional petroleum fuels, such as biodiesel, electricity, ethanol, hydrogen, natural gas, and propane.

Research Motivation & Objective

- **On-road heavy-duty vehicles** (HDVs)
  - 24% of GHG emissions in the US transportation sector
  - Deleterious effects of the criteria air pollutants (e.g., NOx, PM, and CO) on public health

Encouraging HDV fleet operators** to adopt **alternative fuel vehicles** (AFVs) can be **one of the promising solutions

*However, **heavy-duty AFVs** present a **very marginal share** of the total of HDVs (e.g., **4%** in California)*

- **A better understanding of HDV fleet operator perspectives** towards **alternative fuels**
  - Basis for developing effective policy suggestions & tech recommendations

- **However, there is scant research** focusing on **heavy-duty AFV adoption behavior** especially from fleet purchase decision maker points of view

- This research aims to **build a theory regarding alternative fuel adoption behavior from HDV fleet operator point of view** based on both **existing literature** and **new empirical data**

2

Initial Theoretical Framework Based on Literature Reviews

Bae, Y., Mitra, S.K., Ritchie, S.G., 2019. Building a theory of alternative fuel adoption behavior of heavy-duty vehicle fleets in California: An initial theoretical framework. In: 98th Annual Meeting of the Transportation Research Board. Washington DC, United States.

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Initial Theoretical Framework

- **Objective**: To facilitate a conceptual understanding of organizational behavior of AFV fleet adoption, which serves as theoretical background for this research
- **Methods**: Examining and re-designing existing frameworks centering on an organization's innovation adoption behavior, and synthesizing findings from a literature review on light-duty and heavy-duty AFV fleet adoption studies

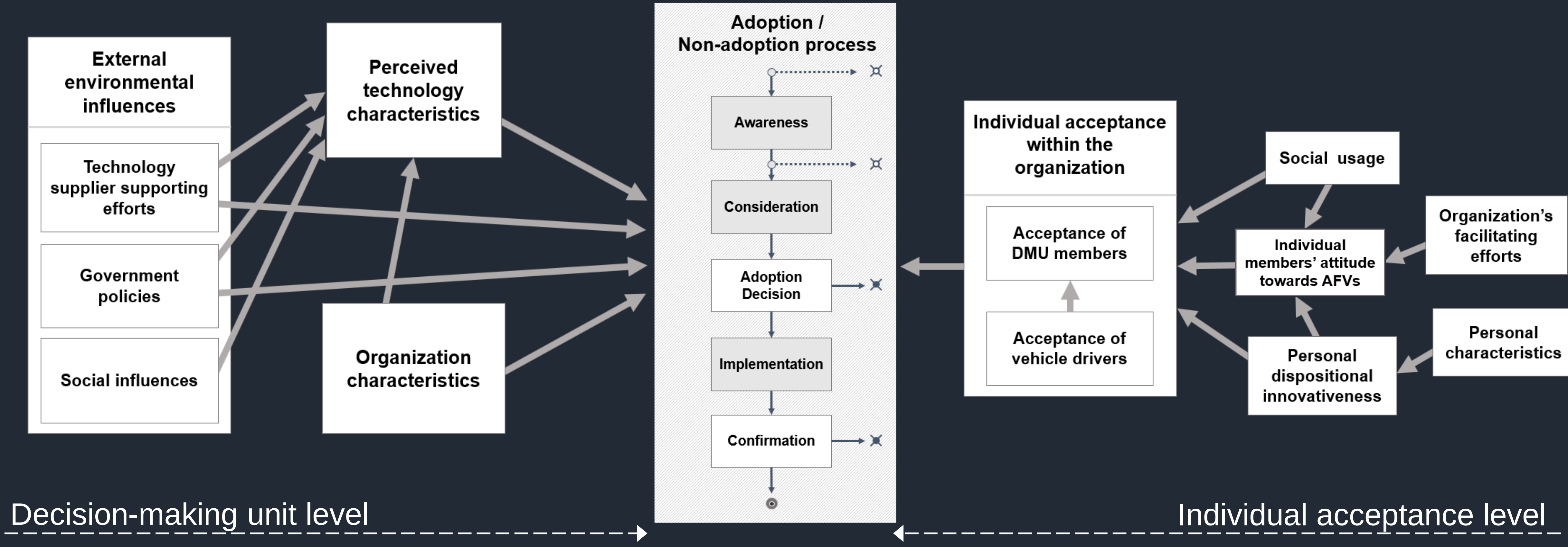
1) Innovation in Organizations in the Diffusion of Innovation theory (Rogers, 1983)
2) Technology–Organization–Environment framework (Tornatzky & Fleischer, 1990)
3) A multi-level framework of organizational innovation adoption (Frambach & Schillewaert, 2002)

a) Database: Transportation Research International Documentation, Transportation Libraries Catalog, Google Scholar, SCOPUS, ScienceDirect, and JSTOR
b) Search Phrases: "alternative fuel vehicle*" combined with "fleet", "organization*" or "commercial" in further combinations with "adoption", "purchase", "demand", "willingness to pay", "acceptance", "interview" or "survey"

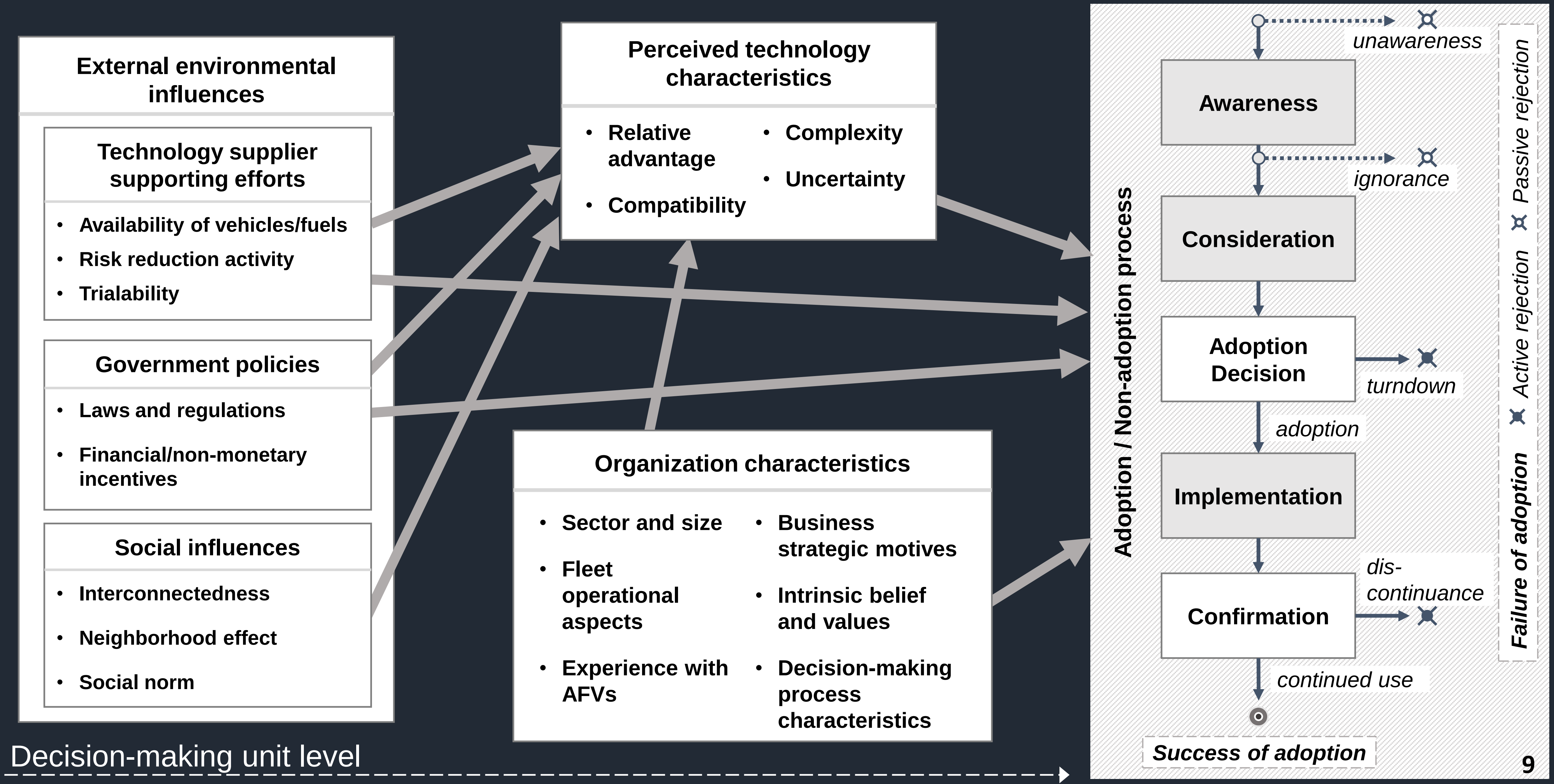
→ 34 papers in total

Initial Theoretical Framework

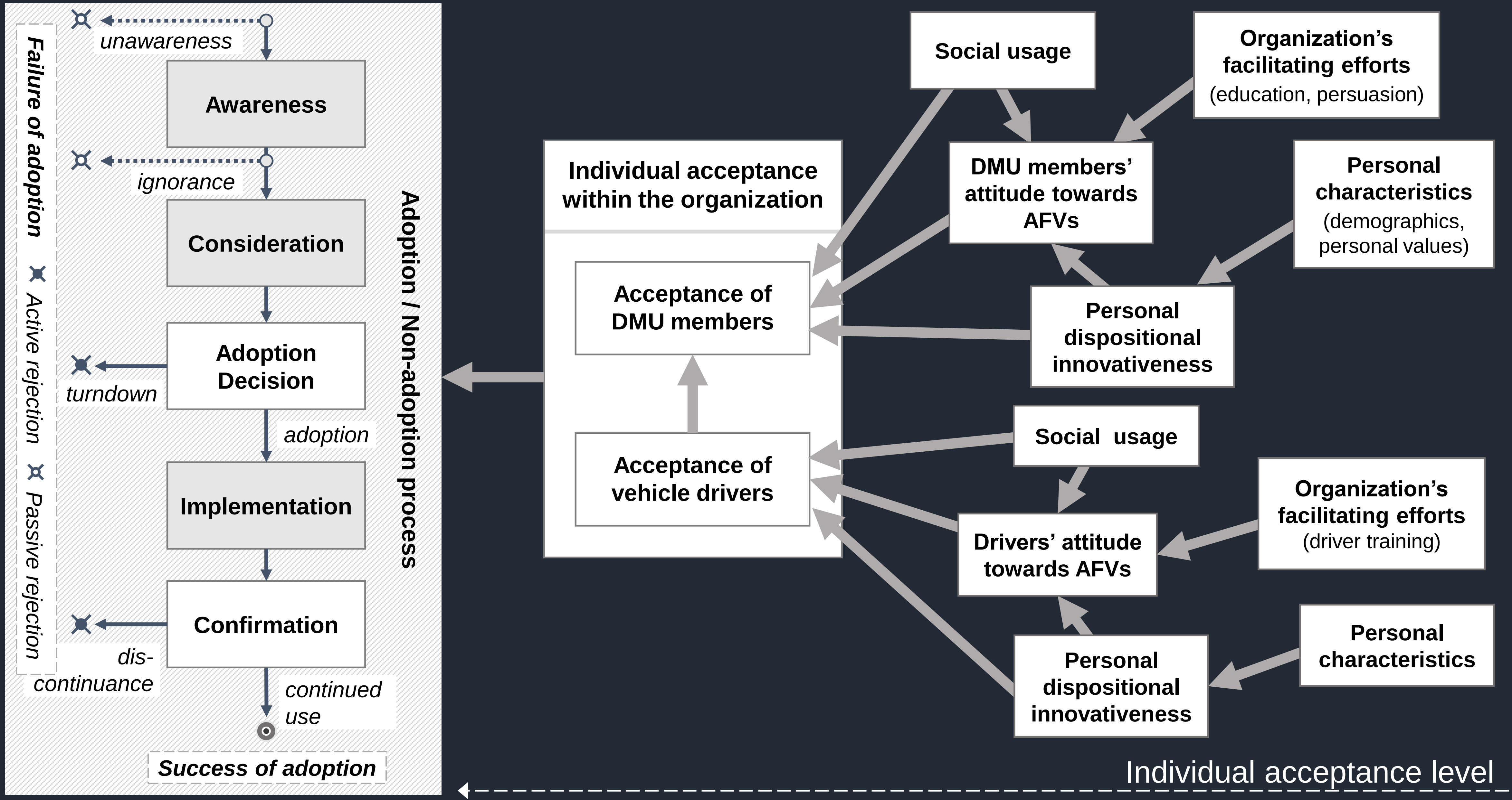
- **Overall Structure**:
  1) A five-stage adoption process
  2) Sub-frameworks at the decision-making unit (DMU) level & the individual (e.g., vehicle driver) acceptance level



Initial Theoretical Framework: DMU Level

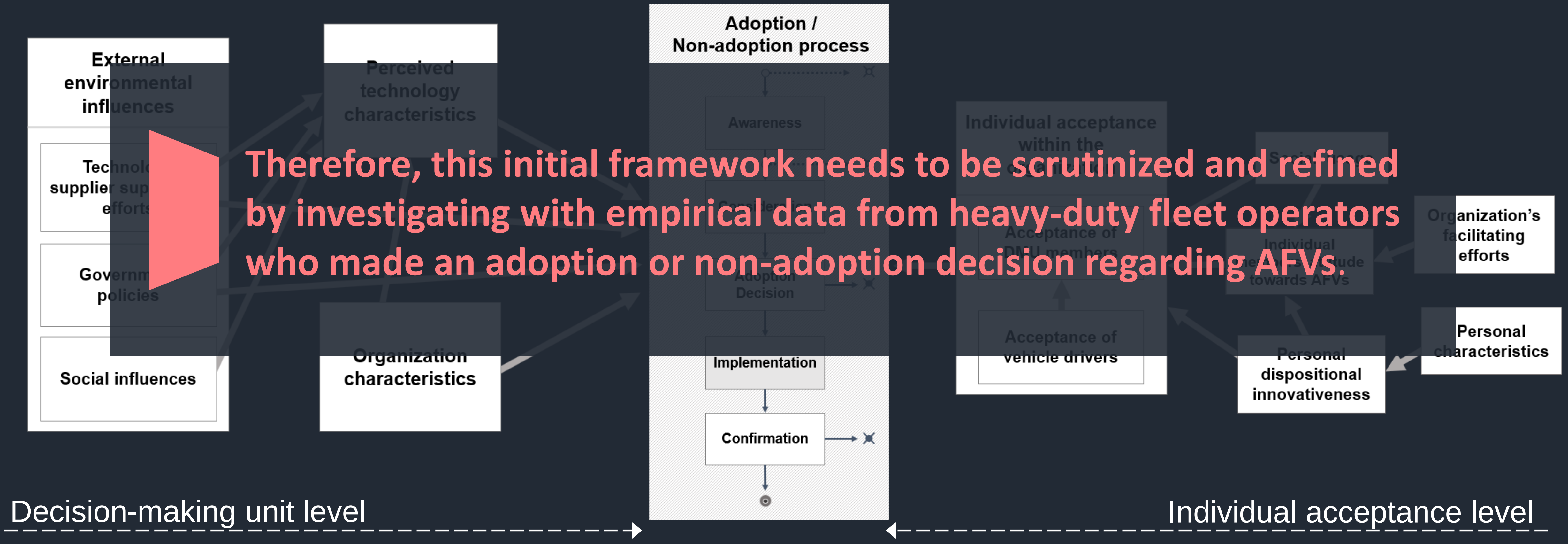


Initial Theoretical Framework: Individual Acceptance Level



Initial Theoretical Framework

- **Contributions:** This initial framework can help organize concepts and explain phenomena that would exist in such fleet behavior, which theoretically contributes to understanding of the research topic.
- **Limitations:** The frameworks based upon literature reviews should be examined, refined, and tested with empirical data.



Therefore, this initial framework needs to be scrutinized and refined by investigating with empirical data from heavy-duty fleet operators who made an adoption or non-adoption decision regarding AFVs.

3 Qualitative Research Approach

Qualitative Research Approach

Qualitative research approach

- An inductive strategy of generating a theory informed by data (Bryman, 2012)
- Suitable to initially explore a phenomenon
- A better chance of being relevant to the context of the research topic (Creswell, 2003)
- A more in-depth analysis than quantitative methods (Yin, 2009)

Semi-structured interviews

- Thorough understanding of the topics
- Flexibility for interviewers to explore the context of the topic
- Much more space for interviewees to answer from their own perspectives and in their own words

California as a case study

- The **most populous** state with over 39.5 million residents (U.S. Census Bureau, 2019)
- The **second largest GHG emitter** among the 50 states, with a share of 7% in 2017 (U.S. EIA, 2021)
- The **freight transportation system**, in which HDVs are one of the main components, being responsible for **one-third of the jobs** in the California economy (State of California, 2015)
- Recognized as a **national leader** with its progressive goals, plans, and actions in **reducing emissions.**
- As of December 2018, about **639,455 HDVs** (≥ 14,000 lbs) are registered in California, including about **28,481 AFVs (4.5%).** In terms of a fleet-level analysis, **3,504 fleets (1.9%)** use one or more alternative fuels among **186,857 HDV fleets.**

Stratified Purposeful Sampling

- **Sampling strategies**
  - HDV fleet operators who considered alternative fuel adoption and made a decision of adoption or non-adoption
  - Public vs. private ▪ Business types ▪ Fleet size
  - Whether or not the organization is subject to any regulations requiring AFV purchases
- **Further efforts**
  - Project reports
  - An interview question about any alternative fuels considered but rejected (active rejections)
- **Final Sample**
  - Twenty organizations
  - A total of 29 adoption and 42 non-adoption cases across various alternative fuel technologies, including natural gas, propane, electricity, hydrogen, biodiesel, and renewable diesel options

Classification	Number of organizations (n = 20)		Classification	Number of organizations (n = 20)	
Public vs. private			**Heavy-duty AFV adoption status** [a]		
Public	11	(55%)	CNG	18	(90%)
Private	9	(45%)	LNG	3	(15%)
HDV fleet size			LPG	4	(20%)
> 100	13	(65%)	Electricity	2	(10%)
20 to 100	5	(25%)	Hydrogen	1	(5%)
≤ 20	2	(10%)	Renewable diesel	4	(20%)
Fleet vocation			**Heavy-duty AFV non-adoption status**		
Various public services	7	(35%)	CNG	1	(5%)
Refuse trucks	5	(25%)	LNG	9	(45%)
School buses	2	(10%)	LPG	5	(25%)
Transit buses	2	(10%)	Electricity	11	(55%)
Local delivery	2	(10%)	Hydrogen	6	(30%)
Freight trucking	1	(5%)	Biodiesel	8	(40%)
Paving work	1	(5%)	E85	2	(10%)
Number of alternative fuel types adopted			**Refueling/Recharging facilities**		
One	10	(50%)	Have their own on-site	14	(70%)
Two	7	(35%)	facilities		
Three or more	2	(10%)	Rely only on off-site	5	(25%)
None	1	(5%)	station(s)		
Year of the 1st heavy-duty AFV purchased			Will build their own	4	(20%)
After 2015	3	(15%)	on-site facilities		
Before 2015	17	(85%)	**Subject to AQMD or CARB fleet rules** [b]		
			Yes	13	(65%)
			No	7	(35%)

Interview Data

❖ Data

- Eighteen one-on-one interviews between July 2018 and April 2019 with key individuals who participate in the fleet purchase decision-making process
- A set of 13 standard interview questions
- Via a phone or in person
- 1 hour 12 minutes on average
- Two recent project reports published after 2017

❖ Some of the Interview Questions

Q “How many vehicles does your organization own or operate?; Among those vehicles, do you have alternative fuel vehicles in your fleet?; What are the vocations of the vehicles in your fleet?”

Q “Who are the key people for making fleet purchase decisions?; Who is involved the decision process?; What role do they play?”

Q “What factors influenced your fleet purchase decisions?; Were there any factors which made you more willing to or more hesitant to purchase AFVs?”

Q “What laws or regulations affected your AFV purchase decision?”

Q “During the decision-making process of purchasing [the AFVs mentioned in Q1], were there any other fuel technologies you considered?”

Content Analysis / Thematic Analysis

❖ Content Analysis

- Involves a systematic coding process, extracting categories, and identifying themes from these categories so as to answer the research questions and to make replicable and valid inferences from texts (Krippendorff, 2004)

- In case the interview data have a direction (e.g., positively or negatively stated) and strength (e.g., implied, explicitly stated, and emphasized)

❖ Thematic Analysis

- A method for identifying, analyzing and reporting patterns and themes across qualitative data (Braun & Clarke, 2006)

- In case the interview data contains narrative descriptions about their experiences and perspectives

Procedure of Content Analysis

1. The interview data were **initially coded using *ATLAS.ti*** that assists in managing numerous codes (i.e., discrete units of meaning) and their associated quotations
2. Among a long list of codes, those with related meanings were combined into discrete textual categories, by which an **interview data abstraction sheet** was created
3. **Two coders independently** filled in **the data abstraction sheet** using their own notes and the interview data (e.g., existence, sign (“+”, or “-”), strength (“1”, “2”, or “3”), and relevant quotations)
4. To ensure **inter-coder reliability** of the findings, **Krippendorff's *α*** was computed
5. The remaining **discrepancies between the two coders were resolved by a third coder** who participated in this study
6. Through **a series of discussions** between the coders with agreed categories and relevant quotes, **themes and hypotheses** were identified
7. Consequently, both **quantitative** and **qualitative analyses** were **agreed and verified** by the researchers participating in this study

4 Results: 12 Main Insights

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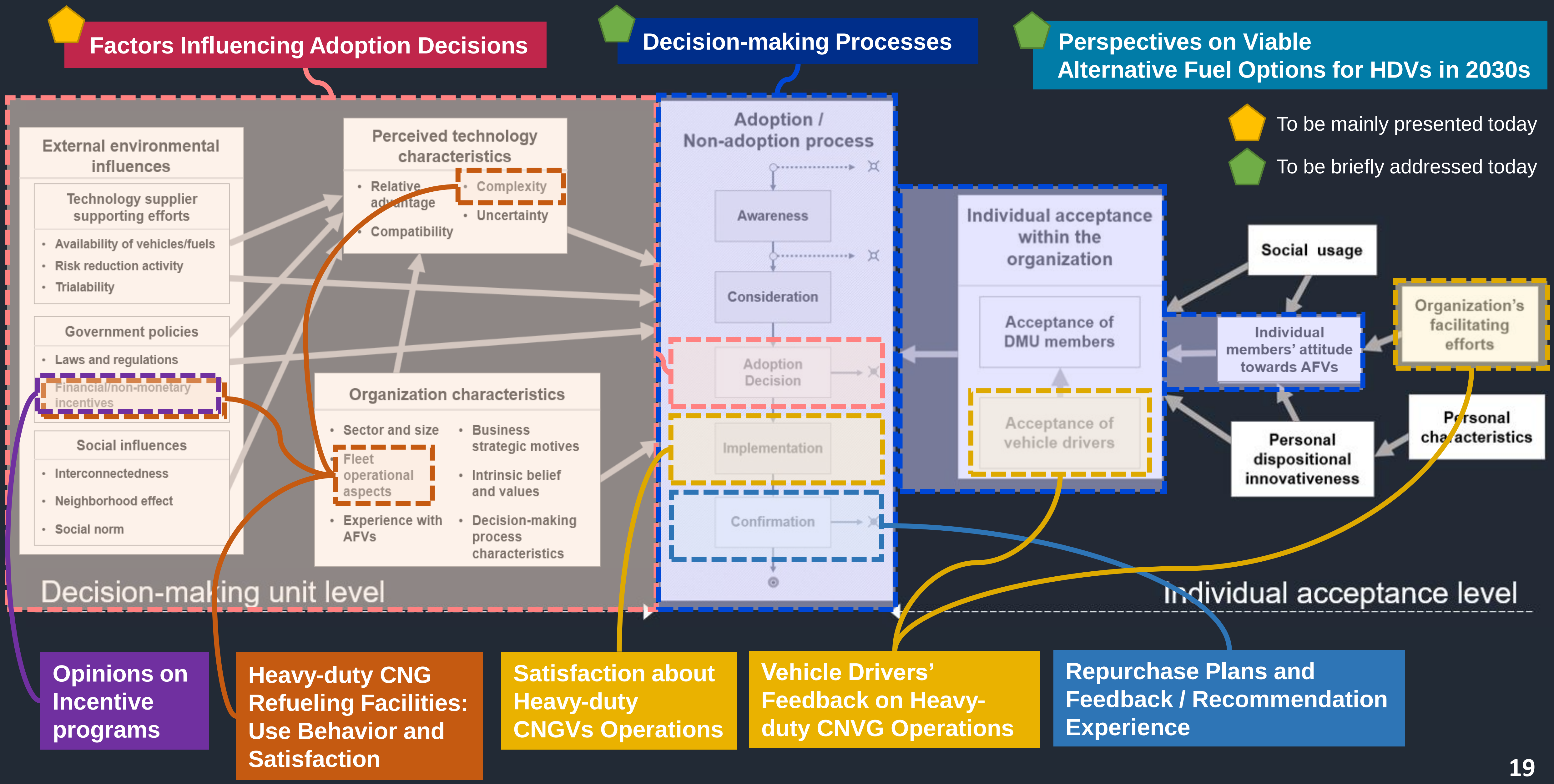
Participating HDV Fleets: Alternative Fuel Adoption Status

Organizations / vocations		01 school bus	02 various	03 various	09 various	10 various	13 various	15 various	16 various	17 refuse	19 transit bus	20 transit bus	08 truck-ing	18 paving	04 delivery	05 delivery	11 refuse	06 refuse	07 refuse	14 refuse	12 school bus
Fleet Characteristics [a]	Sector	Public											Private								
	Fleet size	Medium		Large									Small		Medium			Large			
	On-site fueling/ charging	CNG	(CNG)	CNG	CNG	CNG, LNG, ELEC	CNG	CNG, LNG		CNG, LNG	ELEC	H2	(CNG)		(CNG)	CNG	(CNG)	CNG	CNG	CNG	LPG
Alternative Fuels	< 15 AFVs or New								< 15 AFVs			< 15 AFVs	< 15 AFVs, New		< 15 AFVs, New						New
CNG		A[b]	A	A	A	A	A	A	A	A	A		A	N	A	A	A	A	A	A	A
LNG		N		N	N	A→N	N	A→N	N	A			N				N				
Electricity		N		N	N	A	N	N	N		A		N		N			N	N	N	
Hydrogen		N		N				N	N			A	N								N
Propane (LPG)		N	N	N		A			N				N						A	A	A
Ethanol									N										N		
Biodiesel					N	N	N	N	N				N						N		N
Renewable diesel				A		A	A	A													
Any other alternative fuels than CNG		N	N		N		N								N	N	N				

- "Large": >100 vehicles
- "Medium": 20-100 vehicles
- "Small": ≤ 20 vehicles
- "parentheses" for on-site fueling/charging: on-site facilities will be constructed
- "<15 AFVs": the total number of heavy-duty AFVs, including both those are being currently operated and those to be expanded, will less than 15
- "New": the year of the first heavy-duty AFV purchased was after 2015
- A : an alternative fuel adopted
- N : not adopted after consideration
- A→N : adopted before, but being migrated to another fuel option

Initial Framework Improved by Qualitative Research



Main Qualitative Insights

1 Perceived technology characteristics, mainly in terms of functional suitability, monetary costs, fuel infrastructures, and vehicle reliability/safety, are evaluated in a comprehensive approach for heavy-duty AFV adoption decisions.

The vehicles need to "*meet our operational requirements*" (Org. 17) and "*fit and work in the areas that we need it*" (Org. 7)

"*CAPEX and OPEX - how much does it cost and what it cost to run*" (Org. 14)

"*Probably the only operational issue that we have to be cognizant of at these five sites that have the CNG buses is just the availability of fuel*" (Org. 12)

The vehicle should "*be operated safely for the life cycle of the vehicle*" (Org. 10)

Main Qualitative Insights (cont)

2 Organizational intrinsic values, such as corporate social responsibility, environmental consciousness regarding diesel HDV emissions, or progressive efforts in demonstrating new technologies, as well as business strategic motives, such as contracts with municipalities, were strong motivators to overcome the major barriers (e.g., financial obstacles, uncertain functionality) to heavy-duty AFV adoption.

"If I prioritize them [the influencing factors], number one would be the environmental impact that they have. [...] They (CNG vehicles) would be better than [diesel vehicles]. […] It's about 90 percent reduction [in NOx]" (Org. 4)

"Everybody's concerned about global warming and pollution and environment, so, you know, just doing the right thing is probably the biggest driver" (Org. 14)

"My customers, mainly the municipalities […] They are more receptive to people that are running green vehicles […] It (CNG vehicle) helps us out in our contracts. So, it gives you just a step up above your competitors if you're running natural gas […]" (Org. 8)

Main Qualitative Insights (cont)

3 Governmental regulations requiring AFV or ZEV purchases in California, combined with a narrow range of available AFV models, have created constrained fuel choice circumstances toward a certain fuel option for some HDV fleets.

> *"The decisions about the alternative fuel are forgone. We are affected by AQMD rules 1196, what's called fleet rules. We're mandated. […] The only alternative in 2009 was compressed natural gas vehicle"* (Org. 2)

- The actual effect of regulations..?

> *"If there were no such rules, we would buy diesel due to the incremental costs"* (Org. 2) M *(On-site)*
>
> *"[If there were no such rules…] I would actually diversify a little bit more"* as operating both alternative and conventional fuels *"would be for the safety [of the fleet operations] during emergency"* (Org. 1) M On-site
>
> *"[without such regulations]*, we'll still continue…" (Org., 7, 15, & 17) L On-site

Main Qualitative Insights (cont)

4 Financial incentives have assisted HDV fleet alternative fuel adoption by reducing costs for purchasing the vehicles and supporting construction costs of on-site fueling/charging facilities.

> *"The [CNG] vehicles that we're purchasing are about $225,000 a piece. Our standard conventional diesel trucks are about $115,000 to $125,000. So, it's almost two to one"* (Org. 8)

> *"[…] because of the grants that were available here locally through our air district, that enabled us to do a lot of migration (to NGVs)..."* (Org. 10)

> *"Certainly that [NGVIP incentives] influenced the decision […]. I don't think that we would have otherwise purchased those (CNG) buses had we not had the financial incentive that was offered"* (Org. 12)

Main Qualitative Insights (cont)

5 Any unmet criteria found for a heavy-duty AFV, including unsuitable functionality, reliability/safety issues, unacceptable financial costs, or increased operational complexity due to insufficient refueling/charging infrastructures, resulted in non-adoption decisions.

"They (electric vehicle) don't have range" needed for a school bus (Org. 1); *"they are so heavy" with a limited payload* (Org. 8); *"the capacity it can haul is insufficient" for refuse trucks* (Org. 15); *"there's not an electricity grid out there in place right now (…) "* (Org. 8)

"We have difficulties working with those (LNG duel-fuel) vehicles because the fuel has to be basically cryogenically kept (…) That created issues for maintenance. (...) The fuel tanks would vent if the temperature wasn't fuel locked" (Org. 9)

"It (biodiesel) is just completely destroying those engines" (Org. 8); *"we stay away from"* biodiesel and use renewable diesel instead (Org. 10 and 13)

"We have to make sure our tanks are full, especially if we have some longer routes. [...] The availability of gasoline or diesel is still, even in a state like California, so much more available than what it would be for propane or CNG" (Org. 12)

Main Qualitative Insights (cont)

6 If an organization has already committed to a specific fuel option, typically with a large investment in fueling/charging facilities, it may reject any other alternative fuel options – except for a few large fleets which desire to diversify fuel options.

> *“Because we purchased and spent a lot of money on this CNG station here and CNG fast-fill, [...] I am not willing to take the budget for electric vehicles right now. That will not make sense” (Org. 1).*

7 Perception of the commercial unavailability of some AFVs for certain HDV vocations (e.g., electric refuse trucks, hydrogen hauling trucks) was cited as one of the primary reasons for non-adoption decisions.

> *“I just don't see that [Electric refuse trucks] happening. Not yet, anyway.” (Org. 7)*

Main Qualitative Insights (cont)

8

While many participating fleets were found to have formalized processes with detailed cost analyses and/or written rules, several participating organizations relied neither on detailed cost analyses nor written protocols.

> *"It's all cost analysis. […] If it doesn't affect your bottom dollar in a positive way, then it doesn't make sense to do"* (Org. 8).

> *"The decision is all pretty subjective"* (Org 14)

Main Qualitative Insights (cont)

9 ***(Battery electric HDVs in 2030s)*** Many participating organizations regarded electric HDVs as promising because the technologies are advancing, produce zero tailpipe emissions, and are in line with the state's direction.

> *"I think [an electric HDV] is going to have adequate power to operate all the functions necessary to operate a collection vehicle, [...]"* (Org. 6)
>
> *"My priority would eventually get that zero emissions, [...]"* (Org. 1)

Nonetheless, various concerns and uncertainties were reported relating to the vehicle's functional suitability, required charging infrastructure, vehicle availability, total life cycle emissions, and total cost of ownership.

> *"I think electric is coming a long way just once again with batteries"* (Org. 3)
>
> *"From a practicality standpoint, heavy-duty electrification, it's going to be a hard sell any time soon, because of the charging infrastructure and demand charges potentially from our electric utilities [...]"* (Org. 10)

Main Qualitative Insights (cont)

10 ***(Hydrogen HDVs in 2030s)*** Several organizations addressed hydrogen's positive or negative aspects equivalent to those of electric HDVs.

> *"Electric and hydrogen HDVs remains to be seen [in the 10-20 years down the road]"* (Org. 15)

> *"[Technology providers] are just scratching the surface on the hydrogen. [Only t]he concept vehicles out"* (Org. 8)

Meanwhile, hydrogen HDVs were positively viewed as a practical and economical fuel option when being produced from renewable sources.

> *"10 or 20 years down the road, I think we're going to have hydrogen. Because it's a practical fuel, it's already coming to market. We just have to have more of it produced from renewable sources regionally, not just trucked in like it is now. It can be produced economically"* (Org. 10)

Main Qualitative Insights (cont)

11 ***(CNG HDVs in 2030s)*** Many participating fleets, particularly those already adopted CNG, regarded the fuel as a viable choice in 2030s, mainly due to the fact that they previously invested in the vehicles and on-site fueling facilities.

> *"we would only be heavily using CNG vehicles only because we have invested in the infrastructure, and we've invested in the conversion. I can't see in the next 10 to 20 years switching to a different type of alternative fuel"* (Org. 9)

However, some organizations offered partially neutral remarks that CNG was a transitional fuel, ultimately towards electricity.

> *"I think that the natural gas is a real transitional fuel. […] from really dirty diesel to cleaner electric […but…] The foreseeable alternative fuels for me are still CNG"* (Org. 2)

Meanwhile, one pointed out that CNG is not in line with the state's direction.

> *"[regarding] what future funding is, right now, […] CNG vehicles and CNG Infrastructure are not on the radar"* (Org. 1).

Main Qualitative Insights (cont)

12 ***(Other Remarks on Viable Fuels in 2030s)*** Though mixed viewpoints from the participating fleets, one addressed that the heavy-duty AFV market in the U.S. will not change much from now without other states' participation and more effective market actions that can attract fleet operators to purchase AFVs

> *"If you look at how, where we've come in the last ten years – it's all market driven. I just don't see a huge demand anywhere else other than California. [...] So, in the next 20 years if nothing changes? I see things very much the same. [...] unless other states are purchasing a lot more trucks and the market opens up and other people jump in"* (Org. 7)

Policy Implications

- **Targeted government research and development assistance for technology suppliers** to overcome any technology issues
- **Financial support from governments** in order to help alleviate the major barriers of high purchase costs at least until mass production results in more affordable purchase prices
- Under long-term and stable visions and directions, provision of **funding along with technical guidance for constructing on-site refueling/charging facilities** to help attract new adopters and secure them in the long term
- **Regulatory requirements** for those fleet sectors that are too indifferent to the benefits of alternative fuel adoption
- Provision of **contractual advantages** or implementation of **contractual requirements for the private fleets that serve public agencies**

Policy Implications (cont)

- **Development and promotion of analytical tools for evaluation of different fuel options**, for example, based on a customizable list of monetary and non-monetary components
- Provision of **opportunities to use a heavy-duty AFV in a trial** for some amount of time with the support of technology suppliers
- **Educational programs targeting fleet operators** to help become aware of the benefits of AFV adoption, and help initiate the decision-making processes
- **Advertisement and promotion of the benefits of AFV technologies for those people involved in the decision processes** as a means to increase their awareness and acceptance towards the technologies
- **Networking and information-sharing events, targeting experienced fleets** and **potential adopters** in diverse business sectors to facilitate rapid distribution of in-depth information about heavy-duty AFVs

5 Conclusions

Summary

- **Understanding HDV fleet operator behavior with respect to adoption of AFVs is critically important** for accelerating diffusion of these innovative technologies, and for achieving societal benefits through reduced emissions and improved public health

- **Investigated HDV fleet operator perspectives and behavior toward alternative fuels**

- **Developed the initial theoretical framework** based on existing literature to facilitate a conceptual understanding of organizational behavior of AFV fleet adoption

- **Investigated organizations that operate HDVs in California** via in-depth qualitative interviews and project reports

- A total of **29 adoption** and **42 non-adoption cases** across **various alternative fuels**, including natural gas, propane, electricity, hydrogen, biodiesel, and renewable diesel options.

- Offered an **enhanced understanding of heavy-duty AFV adoption behavior in organizations**, and identified **technology and policy implications** useful for stimulating the diffusion of the technologies

Limitations and Future Work

- **A quantitative survey of a large representative sample** in an effort to validate the qualitative inferences from this study and thus **obtain more generalized findings**

- Further experimental investigations based on a stated preference survey to **estimate the effect of governmental policies**, such as mandates or incentive programs, on heavy-duty AFV adoption

- **Investigation of passive rejection cases** - how passive non-adopters can become aware of alternative fuel technologies, how they can begin evaluating them as an alternative, and what are triggers and obstacles in such processes

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Thank you

Questions & Comments

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